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FOURTH SERIES.

VOL. XVI—[WHOLE NUMBER, CLXVI.]

No. 92.—AUGUST, 1903.

NEW HAVEN, CONNECTICUT.

1903

THE TUTTLE, MOREHOUSE & TAYLOR CO., PRINTERS, 125 TEMPLE STREET.

Published monthly. Six dollars per year, in advance. $6.40 to countries in the Postal Union. Remittances should be made either by money orders, registered letters, or bank checks (preferably on New York banks).

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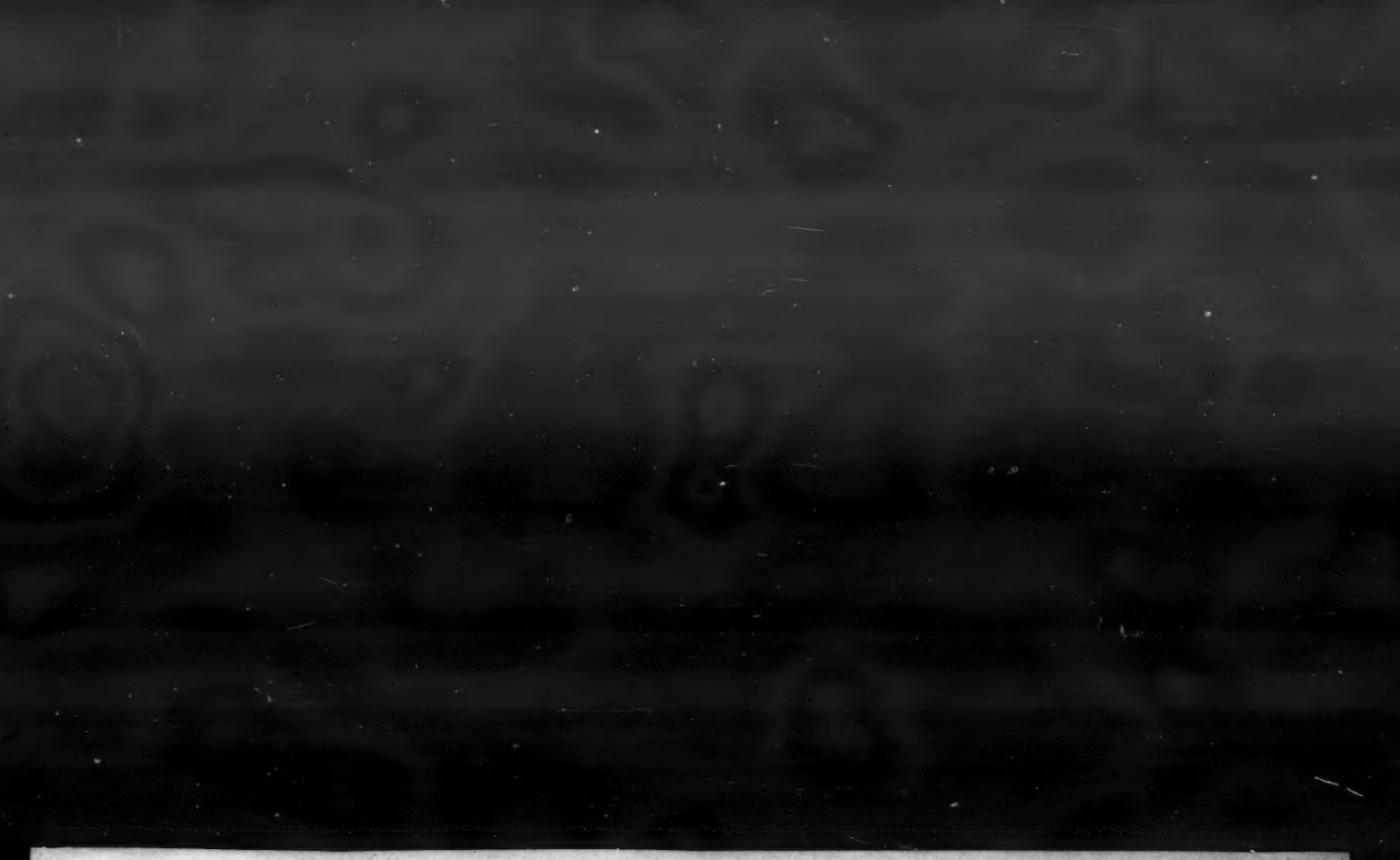

THE

AMERICAN JOURNAL OF SCIENCE

[FOURTH SERIES.]

Art. XI.—*The Mechanics of Igneous Intrusion.* (Second Paper); by Reginald A. Daly.

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Introduction.—In a recent number of this Journal* the writer has presented some of the facts upon which has been based a hypothesis on the development of the larger magma-chambers now occupied by plutonic rocks. There was entailed in the working out of that hypothesis a brief treatment of a necessary corollary—abyssal assimilation of the formation invaded by stock or batholith. The hypothesis was stated in general terms, without a full discussion of some of the fundamental postulates and conclusions and without detailed reference to individual areas. In Bulletin 209 of the United States Geological Survey the application of the hypothesis to a rather complex group of stocks occurring in and about Mt. Ascutney, Vermont, has been made, and some degree of assurance attained that this view of intrusion is there of greater value in explanation than are the older theories of intrusion mechanism.

* This Journal, vol. xv, p. 269, April, 1903.

In the present communication certain other concrete illustrations will be offered along with additional discussion of some of the main premises on which the newer hypothesis is based. Among these premises are: (1) the generally high fluidity of igneous magmas during the time of active intrusion; (2) the normally extensive shattering of the invaded formations at their contacts with plutonic magmas; and (3) the reality of "overhead stoping" of the blocks so shattered and rifted off from wall or roof of the chamber. Concerning the first and last of these premises certain difficulties were hinted at or partially discussed in the former paper, but their importance demands that further attention be paid to them. A note on a particular point referring to the first-mentioned premise may well anticipate the larger division of this paper, which will have to do primarily with contact-shattering in general and with the testimony of several Canadian intrusive bodies as to the validity of the rifting and stoping hypothesis.

The origin and suspension of basic segregations: bearing on the doctrine of the liquidity of plutonic magmas.—At first sight, the common occurrence of basic segregations freely suspended in their rock-matrix always less dense than themselves seems in one way to militate against the idea of high fluidity in igneous magmas. It is true that the mere fact of that particular kind of differentiation calls for the assumption of no inconsiderable degree of mobility in the igneous mass; but the question arises as to how that substance now represented by heavy minerals could be segregated and held up in a less dense matrix possessing such liquidity. That segregations have been so suspended seems clear in the average field occurrence. The question raises a second one as to the relative densities of molten segregation and molten matrix. If it can be shown that in the *fluid* state, matrix and segregation are nearly of the same density, the difficulty disappears and therewith the objection to the theory of high liquidity.

While the variations in thermal expansion of the common plutonic rocks are confined to narrow limits, the experiments so far made on the volumetric increase observed in the passage of single crystalline minerals to the glassy condition (at room temperature) appear to show that the law of even approximately constant ratio of expansion in rock-forming minerals does not hold. The following table taken from Zirkel's Lehrbuch der Petrographie (1893, vol. i, p. 681) synopsizes the results of Deville, Thoulet and others. The percentage decrease in density suffered by the minerals investigated when these pass from the crystalline state to that of cold glass is as follows:

Quartz	16·85 %
Olivine	16·30
Augite	14·18
Hornblende	12·13
Oligoclase	12·19
Orthoclase	10·21
Microcline	9·15
Adular	7·96
Sanidine	7·63
Labradorite	6·28

Barus has shown that, for silicates, the solidification contraction decreases in proportion as the thermal expansion decreases.* Since the thermal expansion is in direct proportion to the decrease of density affecting a crystalline silicate passing to the cold glassy state, it follows that the percentages of the table are in nearly constant ratio to the percentage decreases of density affecting the respective glasses when fused to a thoroughly molten condition. According to Barus, diabase loses 10 per cent in density in passing from rock at 20° C. to glass at 20° C. and its glass loses 7·2 per cent in density in passing from 20° C. to 1400° C., at which temperature it is very fluid. It is highly probable, therefore, that olivine glass would lose in density something like $7{\cdot}2 \times \frac{16{\cdot}3}{10{\cdot}0} = 11{\cdot}7$ per cent in assuming the same temperature of 1400° C. The net result on that assumption would be to give Fogo olivine, for example (spec. grav., 3·381) a specific gravity of about 2·50 at 1400° C. The specific gravity of gabbro at 20° C. becomes, when molten at 1400° C., changed to the following values:†

Spec. grav. at 20° C. Holocrystalline gabbro.	Spec. grav. at 1400° C. Molten glass.
2·90	2·42
3·00	2·51
3·10	2·59

Assuming the approximate correctness of these figures, it is possible to credit the flotation of molten globules of the olivine substance in a highly fluid gabbro or basalt. The rock-matrix would crystallize before the segregation or, at least, would have attained an antecedent viscosity great enough to support the more dense, because crystallizing, olivine. The foregoing reasoning leads to the suggestion for actual experimentation with olivine similar to that so successfully carried out for diabase by Barus. Without such fusion tests it is not

* Bull. U. S. Geol. Surv., No. 103, p. 43, 1893.
† This Journal, April, 1903, p. 277.

possible to tread on sure theoretical ground in dealing with the origin of olivine nodules in basalt, much less in accounting for the more important basic segregations of granites, syenites, etc. It is noteworthy that, besides olivine, augite, hornblende and oligoclase appear to have unusually high coefficients of cubical expansion, and that these minerals are among the commoner constituents of segregations in granites and syenites. The highly important constituent, biotite, has not been, perhaps cannot be, directly investigated in this regard. In the absence of experimental data, the further discussion of basic nodules in the present connection cannot afford very fruitful conclusions. All that seems certain is that the existence of basic segregations does not disprove a high degree of fluidity for plutonic magmas.

Shattering at plutonic contacts.

Among the commonest phenomena associated with the contact-zones of plutonic, igneous rock-bodies (bosses, stocks and batholiths) is that of extensive shattering and disruption of the invaded formations along the contacts. A host of memoirs on exotic granite, syenite, diorite, gabbro and other deep-seated rock-masses contain references to this particular phenomenon. It consists, in its ideal development, of the appearance of two concentric zones of mixed rock occurring between the homogenous main body of igneous material and the encircling country-rock unaffected by any serious mechanical disturbance due to the intrusion. Both zones lie parallel to the average line of contact between the intrusive and the country-rock.

The Zone of Apophyses.—The belt more remote from the intrusive body is generally much the broader of the two and consists of country-rock intersected by more or less numerous apophyses from the main igneous mass. These dikes and sheets are often seen to radiate outward in directions roughly normal to the average line of contact; but others running at all angles to the contact are usually associated. The whole group of apophyses has often thus a reticulate ground-plan and a reticulate vertical section. The portions of the invaded formation bounded by the apophyses are not essentially disturbed from the relative positions they occupied before the intrusion took place. This belt may be called "the zone of apophyses." According to the prevailing views among geologists, the zone owes its origin to a mechanical process of relative simplicity, namely, the injection of the molten magma forced by great pressure into all accessible planes of weakness within the invaded formation. The force may be hydrostatic, due to the weight of the chamber-roof or of part of that roof; or, among other

causes, the energy may be derived from the necessary expansion of volume suffered by the digestion of solid country-rock by the magma.* The development of the fissures now filled with apophysal material may, however, be powerfully aided by a third cause that controls as well the formation of the other of the two zones noted above. It may be believed that a common disrupting force has affected both zones; a brief description of the second zone may anticipate the analysis of the conditions which demand the energetic working of that force.

The Zone of Inclusions; its origin.—The second zone is composed of igneous rock enclosing blocks of the country-rock. As the apophyses, breaking the continuity of the invaded formation, vary enormously in number within the outer zone, so the blocks, breaking the continuity of the igneous body, show the greatest variation in the degree of their abundance. This "zone of inclusions" varies in width from a few meters to three kilometers or more. The blocks, unless very close together and possessing thoroughly massive structure themselves, usually show clear evidence of having been shifted out of their former relative positions in the invaded formation, so that their original orientation is completely lost. There are transitions to the outer zone through the gradual increase in the number of blocks left undisturbed from their original orientation; and there is, of course, no easily fixed boundary between the zone of inclusions and the main intrusive body in which country-rock inclusions are normally absent or very rare. The inner boundary of the zone of inclusions is often difficult to determine in the case of stock or batholith so exposed to view by denudation as to furnish a land-surface close to the former roof of the magma-chamber.

Whatever be the causes of the disruption of blocks now found in the zone of inclusions, those causes are directly connected with the intrusive body itself and are thus not external. The zone is, for example, not due in the normal case to the injection of magma into rock coarsely brecciated by regional dynamic movements in the earth's crust. Movements of that sort tend generally to brecciate rock along straight or open-curve lines and would not necessarily follow the complex, sinuous, closed-curve line of contact such as belongs to a plutonic body. There is certainly, on the other hand, a genetic relation between the zone of inclusions and the replacement of the country-rock by great bodies of intruded magma almost or quite free of foreign fragments. Many authors speak of the inclusions as having been "torn off" or "carried up" by the

* This Journal, April, 1903, p. 289.

ascending magma, without, however, showing the possibility of such a process when correlated with the apparently demonstrated fact of the high liquidity of plutonic magmas. On the assumption of high liquidity at the moment of the immersion of the blocks, they would, in the average case, not remain near the molar contact,* but would sink into the depths of the magma-chamber. It is further impossible to believe that any kind of current action in the magma could carry on a sort of erosion on the chamber-walls, a hypothesis which likewise would fail to explain the constant relation of the zone of inclusions to the molar contact.

Some of the blocks within the zone of inclusions have unquestionably been floated out or sunk from the molar contact after those portions of the country-rock have been completely surrounded by magma of the main body and of anastomosing apophyses. But there are reasons for concluding that apophyses of an abundance, matching the countless inclusions of many internal contact-belts, were not formed simply by reason of hydrostatic pressure forcing magma into original cracks or fissures in the country-rock. The conditions reigning at the contact imply the exhibition of a different source of energy—one which many geologists have incidentally credited with the shattering effect. A clear, positive statement of the case has been given by Crosby in his monograph on the Blue Hills Complex.† The subject is of importance and merits much more discussion than can be brought into the few pages of this paper; it is, moreover, a difficult subject, largely on account of the existing lack of experimental data, and the following treatment of it can lay claim to doing little more than open up the problem and make the attack upon it in a qualitative manner.

Shattering by differential thermal expansion in the invaded formation.—It is manifestly impossible to determine the exact rise of temperature which will occur in a formation at the contact with an invading magma. Both elements, the pre-eruption temperature of the country-rock and the temperature of the magma itself, are partly indeterminate. If the former be regulated by the normal law of the vertical distribution of the isogeotherms, that temperature will be about 200° C at a depth of four miles below the earth's surface—possibly a rather liberally estimated average depth for the upper limit of a granitic magma-chamber. If we assume that the temperature of an intruding magma is approximately that at which the rock resulting from its crystallization becomes thinly molten under plutonic pressures (an assumption apparently justifiable from

* The main contact, that of igneous body *mass* against country-rock *mass*, as distinguished from the minor contact of inclusion and intrusive rock.

† Occasional Papers, Boston Soc. Nat. Hist., iv, 1900, p. 315.

the known properties of lavas and notwithstanding the presence of mineralizing agents), there should occur by conduction *at* the molar contact, a rise of temperature in the invaded formation, of something like 1000° C. That would mean a cubic expansion in the solid rock of between 2·5 per cent and 3·0 per cent, corresponding to a linear expansion of about 0·9 per cent.* The force required to prevent that degree of expansion is equal to the amount of pressure required to compress the rock by the same amount. The coefficient of compressibility for ordinary crystalline and well-cemented sedimentary rock is not far from that of glass, viz.: about 0·0000025 per atmosphere of pressure. Assuming that the thermal expansion should so occur that the volumetric change would be exactly in the reverse sense of the volumetric change observed during compression tests for solids, and assuming that the just mentioned coefficient of compressibility should apply at very high pressures, it follows that the inconceivable pressure of more than one million atmospheres, or about 8000 tons to the square inch, would be required to prevent the expansion of rock raised 1000° C. in temperature. However great the expansion transverse to the plane of the molar contact may be, a large proportion of the force of expansion must pass into the form of compressive strain, developing lines of force in the plane of the contact. If only one per cent of the total force of expansion were applied in that plane, the integrity of the rock must be destroyed, for the crushing strength of rock is in no case as much as fifteen tons to the square inch.

It is extremely difficult, if not impossible, to imagine the enormous and complicated stresses set up in this way. Although the heat of the intrusion would be conducted outwards in all directions from the igneous body, the supposition is reasonable that the temperature reigning only a few hundreds of meters from the intrusive would be very much lower than that at the contact. Differential expansion and consequent intense shearing stresses far above the breaking strain of rock-material might thus be produced. That action would be complicated and intensified by the variable values of heat-conduction in the invaded formation which is always more or less heterogeneous. The following table of relative values calculated from Everett's "Units and Physical Constants" (1879, pp. 101 and 103) shows the importance of differential conduction in different rocks. For ease of comparison all the other values are referred to the conductibility (taken as unity) of calcareous sandstone.

* This Journal, April, 1903, p. 274.

Rock.	Conductibility.
Calcareous sandstone	1·00
Clay slate	1·24
Slate, across cleavage	1·60
Trap	1·97
Micaceous flagstone, across cleavage	2·09
Limestones (mean)	2·44
Granites (mean)	2·51
Sandstones and hard grit (dry)	2·58
Sandstones and hard grit (wet)	2·80
Slate, along cleavage	2·84
Micaceous flagstone, along cleavage	3·00
Sandstone of Craigleith quarry	5·06

The table illustrates the well known fact that, in a rock-mass possessing the plane-parallel structure, the rate of conduction is widely different according as the heat passes along or across the planes of schistosity or cleavage. Such differential conduction and consequent differential expansion may be held responsible for the opening of fissures for the entrance of apophysal igneous matter in spite of the general tendency of the expansion to close preëxisting cavities in the country-rock. The apophyses themselves by virtue of their own high temperature must hasten the destructive action.

Part of the stress-energy set free might be added to that of injection and expended in the minute crumpling of relatively plastic bedded country-rock. Another portion is conceivably expended in irregular and perhaps very complete shattering of the rock, which by that action is relieved from the strains by sudden rending and fracturing rather than by any form of rock-flowage. Still a third portion of the energy might become potentialized as in Rupert's drops, Bologna glasses or certain slickensided rock surfaces,* and only finally expressed as a shatter-force after sudden faulting or other shock in the country-rock had precipitated the destruction, repeating on a large scale, the destruction of a Rupert's drop.

Exfoliation at plutonic molar contacts.—The complexity of these mighty interacting forces is such that the shattering produced by them cannot be referred to simple strain-categories. Experiments and certain observations made in rock-quarries seem to throw light on one of the more important and simpler methods by which disruption of the country-rock may take place. A short statement of the facts derived from each kind of study will serve to place the question of the efficiency of this process in a clearer light.

Reade has given so concise an account of his experiments on the differential expansion of stone that his descriptions of cer-

* A. A. Julien, Jour. Franklin Inst., cxlvii, 1899, p. 382.

tain typical trials may be given in full. "A bar of fine hard light brown sandstone, square-dressed to a smooth surface, measuring between two fixed points 7·346 inches long at 61° F., and roughly speaking $1\frac{3}{4}$ inch by 1 inch scantling, was placed with its ends resting flatways on two supports. The flame of the blowpipe was brought to bear upon the upper surface until it expanded to 7·385 inches. The stone was hot enough to melt solder but not lead—perhaps 500° F. on the top surface. As the blowpipe played upon the stone it became, in places immediately under the flame, momentarily heated on the surface to a bright red heat, and the sharp edges were burnt off; the stone became when cool of a darker brown, but apparently was not otherwise altered by heat. The stone arched upwards against gravity in a most remarkable manner to the extent of $\frac{1}{32}$ of an inch. A second heating brought it up to not less than $\frac{1}{16}$ inch, at which it took a permanent set."* Bars of Sicilian white marble and of oolitic marble, about 14·5 inches in length, were similarly arched $\frac{1}{16}$ inch and permanently distorted. A square slab of Sicilian marble 12 inches on the side and $\frac{3}{4}$ inch thick was placed upon two bars of slate. "It was heated with a blowpipe on the upper surface. The flame was rather small, and was kept mostly near the centre within the circle of dotted lines (shown in Reade's figure), but was also moved about. The slab became very slightly convex. Eventually it cracked. . . . . The crack was the result of the circumferential and radial expansion of the centre part of the slab, within the dotted lines, and shows that a considerable bursting strain was developed."†

The conditions of differential heating in these experiments are analogous to those found at intrusive contacts. The warping of the shell of country-rock immediately adjacent to the molar contact must be of a higher order than in the case of the stone slabs because of the fact that the shell is nowhere free to expand in the plane of the heated surface. The warping would not be interfered with by the pressure of the magma if the latter had access through opening fissures to the outer, cooler surface of the shell. Such fissures would be formed along original planes of fission roughly parallel to the contact, or along shearing planes produced in the same position by virtue of the differential expansion itself. With the intrusion of this apophysal material and the more thorough heating of the warped shell, expansion would be intensified, and, as has been seen, a force would be developed vastly greater than the strength of the rock could withstand. The bending or shearing shell must finally collapse and become shattered into separ-

* Origin of Mountain Ranges, London, 1886, p. 22.
† Ibid, p. 23.

ate masses of solid rock now wholly or partially immersed in the magma.

The process is thus one of exfoliation on a large scale. It is comparable to the rifting action of heat on masonry and on granitic masses "said to have been made a matter of quarry utility in India. It is stated (Nature, January 17, 1895) that a wood fire built upon the surface of the granite ledge and pushed slowly forward causes the stone to rift out in sheets six inches or so in thickness, and of almost any desired superficial area. Slabs 60x40 feet in area, varying not more than half an inch from a uniform thickness throughout, have been thus obtained. In one instance mentioned, the surface passed over by the line of fire was 460 feet, setting free an area of stone of 740 square feet of an average thickness of five inches."* Merrill gives a striking illustration of the exfoliation of granite consequent on thermal expansion and general weathering of the rock composing Stone Mt., Georgia.† Again, the observations made by Niles in connection with operations in several New England quarries corroborate the belief that the exfoliation at plutonic igneous contacts must be well qualified to shatter the invaded formations. At a gneiss quarry of Monson, Mass., the rock is under notable stress due to local crustal compression. A rough measure of the amount of that pressure is found in the sudden visible expansion affecting great slabs of the gneiss which, in the quarrying process, are freed from their beds. "In one mass of rock, 354 feet long, 11 feet wide and 3 feet thick, the amount of expansion after dislodgment was $1\frac{1}{4}$ inches up the slope of the hill. When the fracture by wedging is suddenly and thoroughly made, the expansion takes place immediately, and sometimes the expansive force itself completes the desired work, the stone suddenly springing into the elongated state. Spontaneous fractures also occur, of which one was fully 4 inches wide. On removal of overlying beds, spontaneous upward bendings and swellings of the lower beds also occur, most frequently in the thinner sheets, up to 4 feet in thickness, with formation of miniature anticlinals. The amount of elevation varies from $\frac{1}{4}$ inch to 3 or 4 inches, even in a single afternoon. The span of the arch thus formed is sometimes 50 feet, while some are only 3 feet broad; the crests always trend in easterly and westerly directions, are sometimes ruptured, and are evidently caused by expansive thrust in northerly and southerly directions, since the edge of the sheet at each base of the anticlinal arch remains so closely attached to the underlying bed that no lateral slipping of this edge of the rock could possibly have taken place."‡ Similar exfoliation and arching of limestone is reported by Niles from Lemont, Ill.

* G. P. Merrill, Rocks, Rock-weathering and Soils. p. 182, New York, 1897.
† Ibid, p. 245. ‡ Julien, op. cit., p. 386.

"In one quarry, also, there was an elevation of a part of the bed forming the floor. It was an anticlinal axis of more than 800 feet in length, and its trend was nearly east and west. In its most conspicuous part the elevation was from 6 to 8 inches, and the arch measured from 16 to 18 feet from base to base over the crest."*

Notwithstanding the spectacular nature of these sample phenomena observed in different quarries, the forces engaged in their production are almost insignificant compared with those which must be produced in the shell of country-rock concentric with the molar contact of a still molten stock or batholith. The latter forces may be compared with the force of compression which has so often developed peripheral cleavage and schistosity concentric with molar contacts of stocks and batholiths; but fracture is the necessary product of the one kind of energy applied suddenly, as rock-flowage is the product of the other applied slowly and for a much greater period of time.

Differential heating of the invaded formation will, then, through exfoliation and still more irregular shattering, cause the mechanical destruction of the chamber-vault. If the magma be thoroughly molten, the rock-fragments so immersed in it, will, by the balance of probabilities for the average case, sink in the magma. The new surface of the country-rock so exposed to the hot magma must undergo a similar process. The magma chamber may in this way be gradually enlarged so long as the magma preserves sufficient heat for the purpose. Near the time of final solidification the high viscosity must prevent the sinking of the blocks which are last isolated in the magma. The "zone of inclusions" and its organic relation to the molar contact actually to be observed in plutonic rock-bodies seem to find adequate explanation by this hypothesis.

Illustration from the Madoc-Marmora District of Ontario.

The best published example of a granite stock mapped with the distinct purpose of illustrating a shatter-zone is doubtless that due to the labors of Coste and White in the Madoc-Marmora Mining District of Ontario.† A reduced copy of the map is represented in fig. 1. The legend expresses practically all the information yet printed in connection with the region since the survey was made. Mr. Coste has kindly given the writer certain additional statements on this interesting group of granite bosses; the following quotations are taken from his letter dealing with the matter. "You are quite right in your

* Julien, op. cit., p. 391.

† Geol. and Nat. Hist. Surv. of Canada, Special sheet; ½ mile to 1 inch, published without text, 1886.

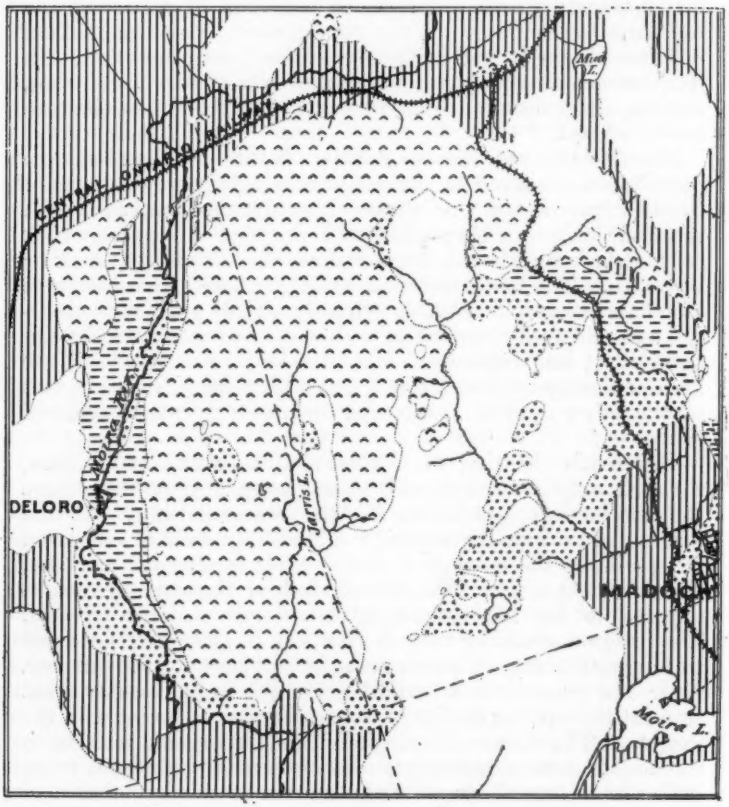

FIG. 1.

Bird's Eye and Black River Limestone; Ordovician.

Intrusive granite.

("Gr. A.B.") Granite enclosing fragments of Archean—Zone of Inclusions.

("A.B. Gr.") Archean altered by the granitic intrusion and cut by many dikes—Zone of Apophyses.

Archean; chiefly crystalline limestone and calc schists.

Scale: 1:126,720.

understanding of the Madoc and Marmora District as a fine example of contact-shattering by an eruptive. The zone on my map '$\frac{\text{A. B.}}{\text{Gr.}}$' is preëminently a zone of apophyses, these being very numerous, running in every direction, more numerous than elsewhere (except in the zone '$\frac{\text{Gr.}}{\text{A.B.}}$') and being mostly fine-grained granite with little or no mica . . . Both zones form decidedly a zone of strong shattering about the intrusive, extending, to a less degree, beyond, all around it, as shown by the separate granite masses and dikes marked (and many not marked) on the map. . . . . The typical granite of that intrusion is a rock of medium-size grains of reddish orthoclase and of round, blue quartz with a little mica, but this passes into a great variety of other rocks."

Mr. Coste holds that there has been some chemical modification of the magma in the zone of inclusions by the incorporation of the limestone and calcareous schists, but has given no details on the evidence.

Owing to the overlap of the Ordovician limestone lying unconformably on both the Archean schists and the granite, the whole story of the shattering cannot be made out at the present land surface; yet the exposure of the shatter-zone is nevertheless remarkably instructive. The general aspect of the map, the breadth of the zones, the existence of patches of the invaded formation lying isolated in the largest stock, and the numerous smaller bosses which occur like satellites about the main granite body—all lead to the conviction that the present erosion-surface is close to the position occupied by the roof of the chamber when the magma of the largest stock was solidifying.

Illustration from the geological structure near Trail, British Columbia.

The second illustration of extensive shattering at granite contacts is selected from the many that might be described from southern British Columbia. The selection has been made not because the phenomena are qualitatively different from those to be seen about other molar contacts in the region, but for the twofold reason that the shatter-zone has here been actually mapped and that the zone is wide enough to be sketched on a map of small scale. The area concerned is shown in fig. 2. It is seen to lie between the town of Trail and the 49th Parallel Boundary with the United States. It is only a few miles east of Rossland and for the most part on the right bank of the Columbia River. This little sketch-map is based on the "Trail Sheet" issued by the Geological Survey of Canada

FIG. 2.

Alkaline granite.

Tonalite-granite of Nelson Batholith.

Shatter-zone of Nelson Batholith.

Rossland Basic Stock.

Rossland Volcanic Series.

Older Volcanic Series.

Scale : 1 : 95,000.

(topography by J. McEvoy; geology by R. G. McConnell, 1896) and on the writer's observations made in the same area, 1902. The heavy terrace-deposits of the Columbia Valley average nearly a mile in breadth and consequently the boundaries of the different formations are there not to be fixed with absolute precision. On account of the thick cover of drift and a dense forest, the same remark applies to the formation-limits indicated in the remainder of the area. The errors are, however, known to be of an order that cannot affect the usefulness of the map for present purposes.

The great complexity of the structure and the high degree of alteration characteristic of the rocks have put still greater difficulties in the way of defining the formations. This is particularly true of the attempt to subdivide the old volcanic rocks which form a large part of the area. There appear to be at least two volcanic rock-groups. The older is the oldest formation exposed in the area, consisting of hard, dark-colored, slaty ash beds interstratified with thick bands of squeezed and much altered basic, amygdaloidal lava-flows, and agglomerates, and cut by irregular dikes and boss-like dioritic, gabbroitic and peridotitic masses, which are probably genetically related to the lavas. As yet the required palaeontological and structural evidences as to the age and thicknesses of these rocks are lacking. In this paper the whole group may be called simply the Older Volcanic Series; the probabilities are, as suggested by McConnell, that it belongs to the Carboniferous or at least to the upper Paleozoic.

Overlying these rocks is a much younger (probably early Tertiary) formation, which, within the limits of the map, is purely volcanic—a group of greatly dislocated breccias, tuffs and flows derived from basaltic and essexitic magmas. Since this formation chiefly composes the mountains northwest, west and south of Rossland, it may be called the "Rossland Volcanic Series." There also appears on the map the eastern extremity of the coarse-grained basic rock-mass marked "gabbro" on the Trail sheet, and referred by McConnell to an origin contemporaneous with that of the Rossland effusives, probably representing the deep-seated portion of the main conduit through which these eruptions took place. This mass is highly variable and has gabbroitic, monzonitic and essexitic facies.

Both of these older series of rocks had been intensely folded, crumpled, and, in places, crushed by mountain-building forces before the intrusion of the great "Nelson batholith" took place. That huge granitic body covers an area of more than 3000 square miles. Its extreme southern end enters the area mapped in the form of a curved tongue narrowing to the southward and terminating in that direction at Violin Lake (see fig. 2).

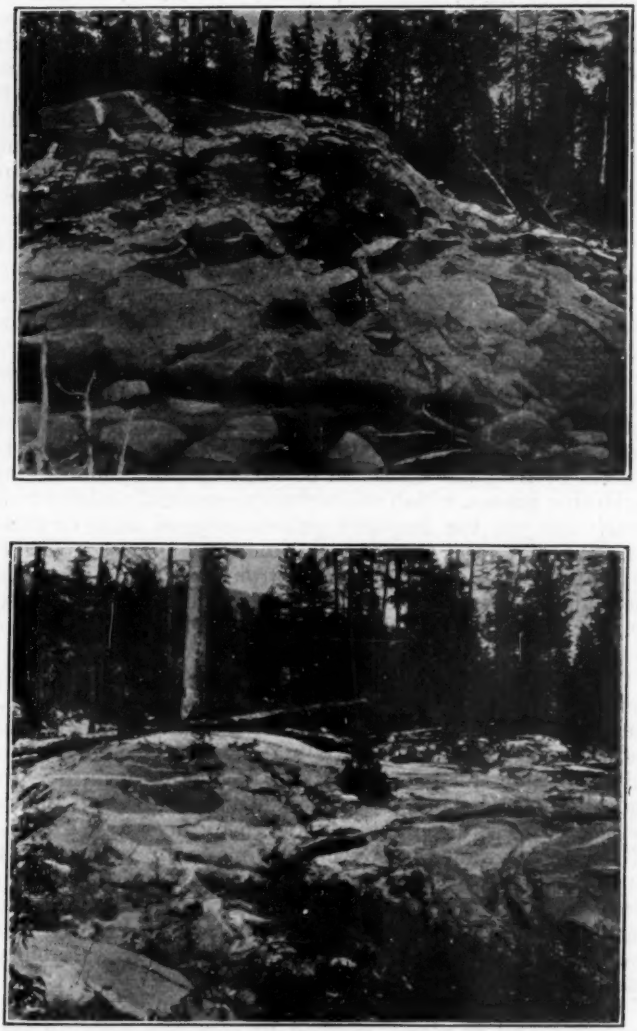

FIG. 3. Two views of the Shatter-zone, Columbia River near Trail, B. C.

Even in this small part of the batholith there is to be seen a noteworthy variability in mineralogical composition. East, west and south of Trail the rock is a gray, coarse-grained tonalite with essential andesine, biotite, hornblende, orthoclase, and

accessory augite. Here and there, with apparently gradual transition, the dominant tonalite passes into a true basic to medium-acidic hornblende-biotite granite. The triclinic feldspar (again basic andesine, near Ab_4 An_3) here becomes quite subordinate and orthoclase assumes its position as the chief light-colored essential. Notwithstanding these and other variations in the character of the igneous body, it is to be regarded as the crystallized product of a single intrusive magma.

The shattered contact-zone which is the matter of interest in the present connection, has been crossed in three places on the line of contact running from the Columbia River to Violin Lake, and has been mapped on the basis of the information thus gained. The shatter-zone has not been mapped on the western side of the batholith since the lack of exposures made search for its limits unprofitable. It is highly probable, however, that the zone exists on that side, though it seems to be narrower than on the southeastern boundary of the granitic tongue.

An unusually fine exposure of the zone outcrops three miles below Trail on the left bank of the Columbia. The local rocks invaded by the magma are a coarse peridotite (hornblendite) and an associated gabbro, both of which apparently belong to the oldest series of rock in the area. For a distance of about 600 meters down the river and thus transverse to the molar contact, the well-washed ledges are composed of a giant breccia. Innumerable, sharply cut, angular masses of peridotite and gabbro are enclosed in the granite and are transected by many veins of the younger rock (fig. 3). The inclusions are of all sizes up to blocks ten meters or more in diameter. Three kilometers to the southwestward the shatter-zone is more than a kilometer in width; the invaded formation is diorite which is markedly schistose in many of the inclusions, becoming at times a true amphibolite. It has proved impossible to separate a zone of inclusions from the zone of apophyses because of their intimate association and because of the massive character of the rocks invaded; hence the two have been combined in the map as a zone of shattering. It is of rather extraordinary breadth in this instance but there is illustrated the same kind of dynamic action as that found along normal granitic contacts.

At the granite-peridotite contact on the river bank, many of the larger apophyses display an interesting case of differentiation. At both walls of each apophysis the essential and normally abundant bisilicates of the granite are absent or are represented by rare shreds or plates of chloritized biotite. The feldspars are here orthoclase, and microperthite with accessory oligoclase-albite. Quartz is the remaining essential. Other veins seemingly contemporaneous with these just described, are composed entirely of the same aplite. The discovery

of the patent differentiation throws light on the origin of the small plutonic bodies of alkaline granite indicated on the map. The edge of one of these appears in its SW corner. That stock covers an area of about 6 square kilometers north of the international boundary and extends over perhaps as many more south of the line. The mineralogical composition, structure and specific gravity are identical with those of the aplite in veins at the river. The alkaline granite is younger than the tonalite since angular inclusions of the latter are to be found in the more acid rock, which sends strong apophyses into the tonalite-granite at various points. Many wide dikes of the alkaline granite also cut the older basic formations south and west of the batholith tongue. The two granitic types seem to have been differentiated in the deeper levels of a common magma-basin after the upper portion of the magma had consolidated.

The application of the above mentioned facts to the general problem of intrusion must be made in the light of the determinations of specific gravities. These are noted in the following table, which gives the results acquired from the use of 30 specimens taken from the granites and from fair representatives of their respective country-rocks.

Rock.	Average Spec. grav.
Tonalite	2·76
Hornblende-biotite granite	2·76
Average of batholith	ca 2·75
Lavas of older volcanic series	2·85
Dioritic rocks associated with the last	2·82
Banded ash-rocks of older volcanic series	2·79
Peridotite at contact, Columbia River	3·22
Rock of Basic Stock at Rossland	2·91
Rossland volcanic series (aver. of 8 specimens of agglomerates, tuffs and flows)	2·85
Younger, alkaline, granite stocks	2·61

It appears from the table that the rock of the main intrusive body, the batholith, is in every case of lower density than any type among the country-rocks exposed in the area. When molten the tonalite-granite would have at ordinary atmospheric pressure a specific gravity of about 2·30*. Under plutonic pressures the same strong contrast of densities between intrusive rock and invaded rocks would persist with but little change. If, then, the magma were thinly molten or even but approximating the condition of perfect fluidity, blocks rifted off from the shattered wall must sink in the magma. The presence of the existing zone of inclusions is only explicable on the supposition

* This Journal, April, 1903, p. 277.

of high viscosity in the magma in its latest phase of intrusion. By reason of the enormous pressures in depth, this strong viscosity would not prevent the injection of the magma into the shattered zone. On the other hand, the long, narrow apophyses running out to great distances from the tonalite-granite mass must have been formed in the longer period of high fluidity. To that period of maximum shattering, rifting and stoping, the opening of the magma-chamber is to be referred.

Since the specific gravity of the younger granite averages but 2·61, and since the stocks of that intrusive have invaded formations practically identical with those displaced by the tonalite-granite, the foregoing argument applies with equal or greater force to the later intrusions. The shattering is again found about these stocks, but it is much less impressive than it is along the S.E. contact of the batholith tongue—perhaps because of the smaller size and more effective stoping power of the alkaline granite bodies.

Stability of the Roofs of Magma Chambers.

The problem remains as to how far in a vertical direction such stoping has gone in the case, for example, of such an immense batholith as that represented in the Nelson granite. Did the destructive action go on until the magma had worked its way to the earth's surface? Was there at any time an extensive foundering of the thinned crust overlying the batholith? Is plutonic energy so nicely balanced with, or controlled in its exhibition by, the enormous amount of work to be performed in opening a batholith chamber that the stability of its vault is never endangered by prolonged stoping? There seems to be no evidence of such foundering and world-shaking catastrophe in the later geological ages or even in Paleozoic times. According to Kelvin's classic speculation there has occurred a great break in the history of the earth. That break was coincident with the final encrustation of the planet as it cooled from a molten state—"the date of the first establishment of that *consistentior status*, which, according to Leibnitz, is the initial date of all geological history."* Kelvin has concluded that previous to final, complete encrustation, the earth attained its present high rigidity by the submergence of the partial crusts produced by the freezing of a less dense fluid mass. The close knitting together of these foundered crust-blocks thus afforded a pre-Paleozoic earth so far cooled down, so strongly bound in its continuous crust, as not to suffer further from the catastrophic violence of wholesale crustal foundering. The speculation leads directly to the further query whether the peculiar structural complexity of the Archean

* Lord Kelvin, Math. and Phys. Papers, London, 1890, vol. iii, p. 297.

areas of the globe may not be related to that process of foundering in its latest, local phase. The refrigeration of the planet must have progressed so far even in the Cambrian period as to prevent a recurrence of life-destroying, world-circling catastrophe. In others words, the possibility of foundering depends, according to Kelvin's view, among other things, upon the amount of residual heat within the earth. By the same view the Nelson batholith takes its place among the post-Archean batholiths which may be believed to have penetrated a crust already sufficiently buttressed through secular cooling so as to withstand the strain due to the differential density of vault and molten batholith. Other general considerations relative to the problem have already been presented in the writer's first paper. All of them are offered rather to emphasize once more the difficulty and importance of the problem than to suggest that a complete solution has been found.

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Art. XII.—*Stellar Revolutions within the Galaxy;* by Frank W. Very.

Attempts have been made to determine roughly the dimensions of the system of stars constituting the Galaxy. By assuming various values for the total mass of the stars and various laws of stellar distribution, approximate mean velocities of bodies moving under the combined attractions of the masses may be deduced and compared with observation. In this way a preliminary conception of the size of the galactic system may be obtained, subject to the uncertainties of the assumptions made.

If we can measure the parallax of a body in one of the galactic streams, a further check on these estimates is given. Such an object we probably have in *Nova Persei* of 1901. All of the novae have been galactic objects. We may safely assume that *Nova Persei* lies either in the main galactic stream, or on a side branch of no great length relatively to the thickness of the stream.

Consistent measures make it certain that the parallax of the star is less than $0''{\cdot}1$. This gives a velocity of expansion for the surrounding nebula which can not be much less than that of light. We have no experimental evidence of any motion of matter that is swifter than light, while cathode rays are known to move with over half the velocity of light and to increase their speed as the vacuum improves. Theory appears to indicate that 300,000 km. per sec. is the limit of velocity which can be produced by the transmission of electromagnetic strains in the ether. Consequently, I shall assume that the nebulous material has been moving, at least in the first part of its course, with this speed. Applying this assumption to individual forms in turn, on the supposition that the initial motion was nearly radial, the maximum radii of the inner and outer nebulous rings ($89''$ and $149''$), and of an arc on the northeast side ($321''$), observed by Perrine on March 29, 1901, 36 days from the outburst of the nova,* give:

	km.
Inner ring, $1'' = (9{\cdot}33\times10^{11})\div 89 =$	$10{\cdot}44\times10^{9}$, $\pi = 0''{\cdot}014$.
Outer ring, $1'' = (9{\cdot}33\times10^{11})\div 149 =$	$6{\cdot}26\times10^{9}$, $\pi = 0''{\cdot}024$.
N. E. arc, $1'' = (9{\cdot}33\times10^{11})\div 321 =$	$2{\cdot}91\times10^{9}$, $\pi = 0''{\cdot}052$.

If the largest motion is definitely assumed to have taken place with the velocity of light, the speed of the material forming the outer ring was presumably one-half as great, or 150,000 km.

* Astrophysical Journal, xvi, 252, 1902.

per sec., and that of the inner ring one-fourth as great, or 75,000 km. per sec.

On September 20, 1901, Mr. G. W. Ritchey obtained a photograph* which shows nebulous material on the south southeast side at a distance of 20″, after an interval of 211 days from the appearance of the nova. Subsequent photographs demonstrate that this material had almost ceased to move by the end of September. We may assume, therefore, that the tangential component of motion has carried the material of this projection along a magnetic line of force nearly to the limiting radial distance; and as the path along such a line is 50 per cent. greater than the direct one, the radial distance on September 20th was:

$$\tfrac{2}{3}\times 300{,}000\times 211\times 86{,}400 = 3{\cdot}65\times 10^{13} \text{ km.},$$

and

$$1'' = (3{\cdot}65\times 10^{13}) \div 1{,}200 = 3{\cdot}04\times 10^{9} \text{ km.}$$

This gives a parallax of 0″·049, agreeing well with the determination from the outer arc of March 29th.

The parallax 0″·05 may therefore be definitely adopted as that of the nova,† and inferentially of that of the Milky Way in its vicinity.

We must next form some idea of the structure of the galactic system, and of the nature of the motions within it.

The investigations of Kapteyn‡ show that when the total proper motion (which forms the best criterion of stellar distance available at the present time) falls between $\mu = 0''{\cdot}04$ and $\mu = 0''{\cdot}05$, the stars having spectra of type II exhibit no tendency to aggregate in the neighborhood of the Milky Way, but those of type I already have a marked preponderance in the lower galactic latitudes. For $\mu = 0''{\cdot}00$ to $\mu = 0''{\cdot}03$, the solar stars also begin to be condensed in low galactic latitudes, while the stars of the first type have nearly seven times as great a density in the Milky Way through a zone 20° wide, as in the galactic zones $\pm 60°$ to $\pm 90°$. Consequently, at a mean distance corresponding to $\mu = 0''{\cdot}04$, the confines of the galactic stream have been entered. If this distance also corresponds to the parallax $\pi = 0''{\cdot}05$, the annual motion of these galactic stars is $1{\cdot}2\times 10^{8}$ km., and the mean linear velocity is $^{1}20/150\times 4{\cdot}75 = 3{\cdot}80$ km. per sec. The mean galactic distance must be five times as great as this, or $\pi = 0''{\cdot}01$, if the mean linear velocities are equal to that of the sun.

* Astrophysical Journal, xv, 129, pl. vi, 1902.

† The most reliable parallax of *Nova Persei* by the direct method is that of Dr. O. Bergstrand of Upsala, in which the effect of the dispersion of the air on the photographic measures is taken into account, giving absolute parallax = 0″·033 (Astronomische Nachrichten, No. 3834).

‡ "On the Distribution of the Stars in Space," Knowledge, xvi, 114, 1893.

Now if the outer and more thinly distributed stars are revolving around great galactic aggregations of sufficient mass to control the general motion, the orbital velocities must increase in the vicinity of the controlling mass. Nevertheless, the dense aggregation of stars itself, having been accumulated during an immense time by gravity, ought to be relatively at rest, because of frequent collisions in the crowded centers. We have seen that stars of the first type are more abundant in the Milky Way. Kapteyn has shown that, between magnitudes 0 and 6·5, there are 19·3 times as many stars of type II as of type I having annual proper motions greater than 0″·50, but only 0·6 as many with proper motions less than 0″·03. This, taken in conjunction with the galactic condensation of the first-type stars, doubtless means, primarily, that there are comparatively few stars of the first type outside the Galaxy; but the small proper motions of stars of the first type may, in part, be due to the smallness of their linear motions. Professor Frost announced at the meeting of the Astronomical and Astrophysical Society of America, held in Washington, December, 1902, that the members of a group of Orion stars (all presumably galactic) have exceptionally small velocities in the line of sight (about 6·5 kilometers per second).* As far as it goes, this observation favors a value for the galactic parallax not far from 0″·03, with the consequences which have been noted. It is desirable that a large number of galactic first-type stars shall have their velocities in the line of sight and their proper motions measured, in order that this important point may be definitely settled.

Starting from these general principles, let us take up the mechanism of the Galaxy more in detail.

(1) Considering the form and structure of the Galaxy: *(a)* From analogy with nebular forms, we may say that the Milky Way is either spiral or annular in its major stream, but in any case it is substantially uniplanar in its leading features. *(b)* The Galaxy, however, taken as a complete system, is divisible into these directed or segregated stellar streams, and subordinate or satellite hosts whose interlacing movements weave a common envelope to the more condensed portions, which is presumably of spheroidal form, and which, judging from analogy with the outer shell of a spheroidal cluster, may extend to possibly ten times the radius of the condensed nucleus.

(2) I assume that, in the stellar universe, there are both

* "Radial Velocities of Twenty Stars having Spectra of the Orion Type": Edwin B. Frost and Walter S. Adams, Science, xvii, 324, 1903. I have applied corrections for the solar motion. "The angular proper motions of these stars are also small." In the Publications of the Washburn Observatory, vol. xi, p. 34, Mr. Albert S. Flint shows that the proper motions of the stars diminish more rapidly than their parallaxes.

movements of approach, produced by the attraction of gravity, and movements away from the attractive centers, probably due in the first instance to explosive agencies; also that the limits of agglomerative and dispersive movements are conditioned by the dimensions of the component bodies taking part in the systematic motion, as follows: (*a*) Agglomeration is characteristic of matter in the condition of collections or swarms of meteors, condensing into stars. Proof follows from the law of gravitation and the admitted existence of meteors. (*b*) Dispersal prevails after a certain limiting magnitude of mass has been attained as a result of agglomeration, presumably owing to instability under great pressure and high temperature, and the increase of explosive or repulsive forces. Proof follows from the structure of stellar clusters, which contain no single star of surpassing magnitude as in the solar system, and from the development of clusters as inferred from the spectra of the stars composing them, the less condensed clusters having more advanced spectra, indicating that the progression of a group of stars is towards more complete separation.

(3) The following are a few of the consequences of a theory of combined stellar concentration and dispersal:

(*a*) Comparative permanence of the potent, controlling, stellar streams, which are the loci of galactic agglomeration, is indicated by theory, since the attractive force increases as the mass enlarges, while dispersal sets a limit to the growth of aggregations, but does not obliterate them. Hence the original centers of condensation survive. In the surrounding regions there is presumably motion controlled from the loci of condensation, and with velocities increasing as the agglomerations are approached; but within the galactic agglomerations relative rest prevails, because in these dense regions opposing motions have been largely destroyed by collisions.

(*b*) Hence dispersal of satellite hosts from centers of dispersal in the galactic belts must produce outlying shells of sparsely distributed stars, and an excessively slow circulation of individual members of the accompanying starry hosts around definite galactic streams, which thus become the axes of a revolution remotely resembling that of a vortex ring, somewhat as a basaltic column resembles a crystal—not that there is consistent direction or parallelism in the orbits, any more than there is in the crystallization, but, on the contrary, a great variety of positions and paths, conditioned only by general agreement in a tendency to helical motion.

(*c*) Although the form of the condensed part of the Galaxy may be either a ring, or some kind of spiral branching from a

center, as suggested by Easton,* the limiting volume which includes the sparsely distributed, but controlled, outlying members of the host, may be approximately a sphere. A different history, or mode of formation, is indicated for the central forms and their surroundings.

(*d*) If velocities occasionally generated exceed the controlling power of the combined mass, such portions escape. Hence instances of this sort can not accumulate, and must be rare.

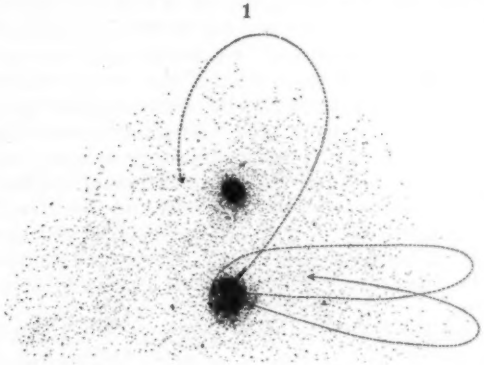

Figure 1 shows the paths of stars thrown off from a central condensation in various directions with velocities insufficient to produce separation from the system. If the direction is such that another branch or condensation has mass enough to draw the return path to one side, the circulation may be around this, rather than around the original member. Owing to the complex form of the Galaxy, perturbations are of a magnitude equaling or excelling the attraction of a parent center.

The revolutions shown are of excessive slowness, and of sufficient duration to allow a majority of the encompassing host to have passed through the stages of development characterized by first-type spectra, and to have attained the solar type.

(4) In order to reach some conception of the dimensions and periods of stellar revolutions around the Galaxy, I propose to take the galactic parallax $= \frac{1}{10}$ of a second of arc, corresponding to a distance $D = 600 \times 10^{12}$ km. in round numbers, as that of the sun from a galactic center of attraction, and to trace some of the consequences. Let D_1 be Neptune's distance from the sun. For a constant mass, the parabolic velocity is proportional to $\sqrt{1/D}$; hence the parabolic velocity from solar attraction at the sun's assumed galactic distance is

* Astrophysical Journal, xii, 136, 1900.

$$U_1 = \left(\frac{D_1}{D}\right)^{\frac{1}{2}} \times 7{\cdot}624 = 0{\cdot}02079 \text{ km.}$$

The velocity of the sun's motion among the stars is about 20 km. (Campbell's value is $-19{\cdot}89$ km. per sec. $\pm 1{\cdot}52$ km.),* and the ratio of the squares of these numbers gives a value for the galactic attracting mass, on the supposition that the solar motion is due to such attraction. If the present solar velocity were that of a circular orbit around a galactic cluster, undisturbed by the attraction of outlying masses, the solar parabolic velocity would be $U = 20 \times \sqrt{2}$; the central cluster must then have a mass 1,850,000 times that of the sun; and the period of one complete revolution would be nearly 6,000,000 years. But if the orbit is a very eccentric ellipse, reaching to the outer boundary of the galactic enclosing sphere, let us say 6×10^{18} km., the period must be lengthened. The circular orbit presupposes a center of attraction nearer than the main galactic stream, and not in its plane, since otherwise the present position of the sun, which is not far from the galactic plane, ought to be accompanied by a motion in the direction of the galactic pole.

Still considering the attraction of a mass $M = 1{,}850{,}000 \times M_1$, situated entirely within the solar orbit (M_1 being the sun's mass), let

perigalacteum ..... = 60×10^{12} km.,
present solar distance.... = 600×10^{12} "
apogalacteum ..... = 6000×10^{12} "

The corresponding velocities are $20 \times \sqrt{10} = 63\frac{1}{4}$, 20, and $63 \times \sqrt{\frac{1}{100}} = 6{\cdot}3$ kilometers per second. The period is nearly 70,000,000 years. With such a recession, however, we can no longer neglect the immense mass of surrounding stars, no matter how symmetrically they may be disposed.

A conveniently simple hypothesis for a first approximation is that the mass is uniformly distributed throughout the stellar sphere, of which we need only consider that part within the sun's actual radius at each moment of its revolution. With such a disposition of material, an individual sun might vibrate, pendulum-wise, on either side of the center, between extreme positions. The acceleration of gravity in such a cluster increases in proportion to the radius, and the velocities fluctuate between narrower limits.

If there are 1,000,000,000 stars, uniformly distributed within a sphere of radius $6{,}000 \times 10^{12}$ km., each star has to itself a volume $9{\cdot}05 \times 10^{36}$ cubic km. The mean distance of the stars

* Astrophysical Journal, xiii, 83, 1901.

is then ten billion kilometers (English numeration). As the distance of the nearest star, *a* Centauri, is forty billion kilometers, the adopted radius of the sphere is too small for the assumed uniform distribution; but for the actual stellar distribution it is not an unreasonable value, because of the concentration of stars in the galactic centers, and provided the number 10^9 is acceptable for the total number of stars. Photographs of long exposure with telescopes having a large ratio of aperture to focal length, increase the number of stars to such an extent that 10^9, or possibly even 10^{10}, will not be an unreasonable estimate. The following considerations, however, prove that, if there be as many as 10^{10} stars concerned in the control of the solar motion, their average individual masses must be considerably less than that of the sun (I assume that the ether is devoid of mass, and that matter outside the Galaxy is on the whole symmetrically disposed, and is separated from our stellar system by such wide vacant intervals that the galactic motions may be treated independently): The solar acceleration of gravity at Neptune's orbit being $0{\cdot}000{,}651^{cm}$ per sec., the galactic acceleration at the distance $D = 6000 \times 10^{12}$ km. is:

$$f = \frac{M}{M_1} \times 0{\cdot}000{,}651 \times \left(\frac{4{\cdot}461 \times 10^9}{6{\cdot} \quad \times 10^{15}}\right)^2$$

$$= \quad 3{\cdot}6 \times 10^{-16} \times \frac{M}{M_1}.$$

Assume $\frac{M}{M_1} = 10^{10}$, and f to be uniform for 200,000 years. The velocity $v = 227$ km. per sec. at the end of this time, attained before one-sixth of the distance to the center of attraction has been traversed, is already larger than the maximum velocity permissible. Hence the attractive mass must be less than $10^{10} \times M_1$.

Let us next try the ratio $\frac{M}{M_1} = 10^9$, with the same radial dimensions. I have shown that the motion of the sun can be accounted for, if the central portion of the sphere within the sun's present radius vector contains less than 2,000,000 stars of the same mass as itself. Since the spherical volume of this space is $\frac{1}{1000}$ of the total volume of the assumed stellar sphere, the supposition of uniform distribution gives 2×10^9 stars for the larger volume; but with central condensation the outer portions of the sphere have not only a more open distribution of stars, but a smaller mass to the unit of volume, and both the number of stars and their mass must be less than 2×10^9. If $n = 1{,}000{,}000{,}000$, and the stars are uniformly distributed, it will take 6,000,000 years for the sun to traverse the distance

from the boundary of its assumed sphere of motion to its present position, and the velocity acquired will be approximately 47 km., or more than twice that assigned from investigations of the solar apical motion.

With a galactic mass of 10^7, and the same dimensions as before, the sun will travel over the path from apogalacteum to its present position in about 19,000,000 years, but the final velocity is less than 15 km. per sec., or probably a little less than the actual one, still not so much smaller but that the increased acceleration produced by central condensation may bring the velocity up to the required amount.

Twenty million stars of the same mass as the sun, after 13½ million years, will give a velocity of 21 km. per sec. with uniform distribution, and more with central condensation.

Extreme condensation is improbable. Professor Newcomb has shown* that, for equal areas of sky, the brightness of the sky in the Milky Way is more than twice as great, but not as much as three times as great, as that near the galactic pole. If the general light of the nocturnal sky is due to small stars, this observation seems to indicate that the stellar distribution is more nearly uniform than is commonly supposed.

Some 20 years ago Professor Newcomb† calculated that 500,000,000 stars with masses equal to the sun's mass, and uniformly spread out in a thin circular layer or disk, $284{,}000 \times 10^{13}$ km. in diameter, will produce a velocity of 40 km. per sec. in a body falling from infinite distance to the center of the system. Such a disposition of attracting masses can hardly be considered a probable scheme of present stellar distribution, and I presume its proposer will prefer to modify it in the light of his own more recent photometric observations. The same mass distributed through a sphere of equal diameter has 50 per cent greater attraction, and central condensation would still farther increase the mean velocity.

Lord Kelvin‡ assumes a uniform stellar sphere with a radius five times as great as mine. This may be a better value than mine for an outer boundary of the galactic system, but comparatively few stars attain it, and the velocity possessed by our sun does not point to so large a recession. Vogel and Scheiner obtained an average velocity in the line of sight of 16·5 km. from fifty-one stars.§ Professor W. W. Campbell, after separating the solar motion, obtained for the numerical average of the velocities of 280 stars in the line of sight ±17·05 km. per sec.,

* Astrophysical Journal, xiv, 297, Dec. 1901.
† "Popular Astronomy," 2d ed., p. 501.
‡ Phil. Mag. (6), ii, 161, 1901; also iii, 1, 1902.
§ Scheiner's "Treatise on Astronomical Spectroscopy," Frost's translation, p. 350, 1894.

whence "the average velocity *in space* of each star in the system is $2 \times 17{\cdot}05 = 34{\cdot}10$ km. per second."* With this may be compared Lord Kelvin's calculation that if 1,000,000,000 stars, each of the sun's mass, started from a state of rest thousands of millions of years ago (a considerably larger time allowance, it will be noted, than has hitherto been admitted), and are now uniformly distributed in a sphere whose radius is $30{,}900 \times 10^{12}$ km., the present mean velocity should be about 50 km. per second.

If we assume that the individual stellar motions at perigalacteum are controlled both in direction and speed by some cluster, branch, or portion of a galactic ring, and that the general stellar sphere has then but little influence, it must, nevertheless, be conceded that at the larger distances and throughout the greater part of the stellar revolutions, if these are eccentric, the general sphere exercises control, and that the subordinate condensations or branches act only by the perturbations which they produce. It seems probable that much greater stellar velocities than those which have been measured, remain to be discovered on the borders of the denser galactic aggregations. Campbell finds that the velocity in the line of sight for stars fainter than the 4·0 magnitude, is about 50 per cent greater than for stars equal to, or brighter than, 3·0 magnitude. These stars, however, were not classified galactically.

Speaking only of observed stellar motions and the *effective* attractive mass which they indicate, it appears that a galactic mass equivalent to 20,000,000 suns like ours, with a moderate central condensation sufficient to quicken the stellar motions in our vicinity by one third of their amount with homogeneous distribution, is a probable value. Stars, presumably belonging to the galactic system, exist in numbers approaching or exceeding hundreds of millions; hence there are either a great many stars of small mass, our sun being larger that the average, or else much the larger number of stars is so situated that the attractions are mutually annulled.

The radius of the stellar sphere surrounding the main streams of the Galaxy and under the control of their attraction, is possibly 30,000 billion kilometers, as predicated by Lord Kelvin; but the solar apogalactic recession does not seem to be so great. The motion in a homogeneous swarm is of the nature of a simple oscillation; and between limits of $\pm 6 \times 10^{12}$ km. with the total efficient mass just given, the movement from one extreme to the other will consume a little less than 30,000,000 years. Such an arrangement, however, can not endure, because the intersecting paths entail numerous collisions near the cen-

* Astrophysical Journal, xiii, 84, 1901.

ter, with destruction of linear motion and the formation of a condensed nucleus. With such a nucleus, assuming a perigalactic approach to 0·01 of the apogalactic distance, or a short-radius swing around some dominant galactic agglomeration, the galactic period of revolution of a star, under the attraction of a mass $M = 20{,}000{,}000 \times M_{\odot}$, may approximate 25,000,000 years. Mr. Maxwell Hall, by combining the positions, proper motions, and parallaxes of a small number of stars for which these quantities have been satisfactorily determined, and assuming circular orbits around a general center of motion, obtained for the length of the "Annus Magnus" 20,000,000 years.* A revision with improved data gave for the period of general revolution 13,150,000 years,† the center of motion being in Andromeda. Kapteyn considers the center of the Galaxy to lie in the direction of Lacerta; and Easton has given reasons for placing this center in Cygnus. The presumption that the orbits are ellipses rather than circles, and ellipses of large eccentricity, which require longer periods, follows from the principles adopted in the present paper, while the solar motion favors Easton's position; and as it is not necessary to suppose that the nearer stars are moving around the same center, arguments from the structure of the Galaxy itself deserve the most weight.

(5) When the proper motions of the stars are charted, the divergence from the apex and convergence to the anti-apex of the sun's way immediately attract attention; but after allowing for this, there is no very obvious preponderance in the residual directions of the true proper motions, either with or across the galactic plane. Upon the hypothesis that the stellar movements have originated in dispersals produced by explosions, this result indicates that the explosive forces have acted indiscriminately in all directions. The primary forces which have given the condensed part of the Milky Way its structure have acted in a plane; but the motions of the outlying stars have probably had a different and secondary origin, and this is further indicated by the advanced types of their spectra.

(6) According to the assumption that the stars have been thrown off from centers of dispersal distributed along the galactic axes of condensation, and that explosive division of stellar masses in the galactic zone is still in progress, the Milky Way must include both stars of great mass, as yet undivided, and large numbers of small stars, together with star clusters resulting from recent division, as well as dark meteor swarms not yet ready for stellar existence. The concentration of mass in a narrowly limited central region may be great, but we are

* "On the Sidereal System," Mem. Roy. Astr. Soc., xliii, 196, 1876.
† Monthly Notices, Roy. Astr. Soc., xlvii, 539, 1887.

unable to distinguish between the relative numbers of large and small stars, and can give no numerical estimate of the degree of (mass) condensation. Scheiner derives a relative numerical condensation of 1:16 for the periphery and center of the great cluster in Hercules,* but Newcomb's ratio of galactic brightness does not favor so marked a variation in the distribution of galactic density, at least not unless there are many dark bodies—incipient novae, not yet ready to shine—situated within the galactic streams. The possibility of such dark bodies must of course be admitted, but no estimate can be made of the amount of matter thus concealed.

(7) If we may assume that the life of a sun surpasses in duration that of a single revolution about the galactic axis, our solar system has endured much longer than is commonly supposed by astronomers, and its age is more nearly in agreement with the time estimates deduced from geological reasoning. The suggestion of a galactic year, embracing many millions of solar years, and perhaps attended by changes in meteoric accessions received in different parts of the orbit, which modify the planetary atmospheres and alter their absorptive power for the solar rays, or change conditions affecting the life of plants and animals, is worth considering. Thus, as Sterry Hunt has shown, the amount of carbon stored up by our earth in the Carboniferous age exceeds that which can have existed at any one time in an atmosphere suitable for supporting life, many times over. Accordingly, during this age, there were probably continual or successive additions of carbon, or its compounds, to the atmosphere; and the carbon came from regions of space richer in this material than any traversed before or since.

The Ice age, which has never been satisfactorily explained, may have been produced in the same way either by changes in the sun itself and its radiant power, or by variations in the constitution of the earth's atmosphere affecting the atmospheric absorption of solar and terrestrial radiation, and thus controlling surface temperatures.

(8) The hypothesis of stellar revolutions around controlling galactic centers may be illustrated by the case of our own sun which is assumed to be well on its way toward perigalacteum.

Since the projection of the Milky Way upon the celestial sphere divides the sphere into nearly equal parts, our sun at present must be near the plane of the ring or spiral of condensation. Also, since the apex of the sun's way is not over 20° from the central line of the galactic stream in Cygnus, the sun is probably moving obliquely at a small angle with the plane of the ring, around some dominant mass. A right line

* Abhand. d. k. Akad. d. Wissensch. zu Berlin, p. 36, 1892.

through this mass, parallel with the sun's motion, will intersect a plane through the sun at right angles to the direction of motion and meeting the celestial sphere in a great circle 90° from the apex, in a point whose projection may lie anywhere on this great circle; but if the motion is actuated by the predominating attraction of a part of the galactic stream, the plane of motion is probably nearly perpendicular to the general direction of the Galaxy on either side of the chief attractive center, because the attraction of the adjacent portions of the galactic stream, if at all symmetrical, will bring the plane of motion into approximate coincidence with a radial plane through the rectilinear axis of curvature of the stream. It is also probable that the dominant region of attraction for our sun lies in the Milky Way not far from the apex of the sun's way.

The projection of a line through the center of attraction, parallel to the sun's path, will be a portion of a great circle through the apex, cutting the Milky Way in Cygnus, and intersecting the trace of the plane through the sun at right angles to the line of motion, somewhere in the constellation Aquarius. The projected line is nearly parallel to the direction of proper motion of our near neighbor, 61 Cygni, which very likely forms one system with the sun.

The axis of orbital revolution can not be placed at present; but as our sun approaches perigalacteum, the apex of motion will recede to a point on the celestial sphere 90° from the Milky Way, and the direction of motion of the apex will then determine the axis of the orbit. Long before that time, however, the present constellations will have been entirely broken up, and only the more general shapes of portions of the Milky Way will preserve a kind of fixity. All that can be said at this time is that the sun has advanced toward the Galaxy from its northern side, passing through its plane to its southern side, and that the sun is now within the stellar coil and nearly in the galactic plane.

Arcturus, Va.

Art. XIII.—*The Little Cottonwood Granite Body of the Wasatch Mountains;* by S. F. Emmons.

The Wasatch Range, from a geological standpoint, is the most important of the many more or less parallel mountain uplifts that go to make up the Cordilleran Mountain System in its widest part—that is, between the latitudes of 39° and 41° N. It has, from the earliest geological time of which we have any record, formed the dividing line between the geology of the west or Pacific slope and of the eastern Rocky Mountains, there being an essential difference on either side of this line, not only in the lithological constitution of the respective geological formations but in their faunal characteristics.

From a Tectonic point of view it is equally important, presenting as it does examples of most of the varied phenomena involved in mountain building, the latest phase having been a great meridional fault which has cleft it in twain, so that its western half is now buried beneath the floor of the Great Salt Lake Valley; it is thus well worthy of the characterization given it by the elder Dana, as "the grandest exhibition of facts pertaining to an individual case of mountain building in geological literature."*

It was in the summer of 1869 that the geologists of the 40th Parallel undertook the geological examination of this range. The two previous seasons had been devoted to geological mapping† of the Desert Ranges of Nevada and western Utah. In these isolated ridges, standing like islands in a great ocean of recently deposited sediments, the rocks were found to be mainly eruptives and members of a great Paleozoic series whose extent, position, and faunal characteristics in the vast region west of the Mississippi Valley were as yet completely unknown, and the facts gathered so far had afforded no clue whatever as to the extent or order of superposition of the different members of this portion of the sedimentary column.

As our weary march across the desert in the season of 1869 had finally, in the month of November, led us along the western foot of this magnificent range through the smiling

* This Journal (3), xlv, 181.

† It is perhaps questionable whether the word "mapping" is the correct term in this place, for at the time no maps of the region were extant and topographer and geologist did their field work side by side. It was not until 1875 that the paleontologists had furnished their final determinations of the age of the various groups of fossils collected and the topographers had completed their maps so that the geological outlines might be laid down upon them.

fields and orchards of the Mormon farmers, we looked with delight at the deep clefts of the many canyons that scored its flanks, foreseeing that here at last might be found a key to the problem that so long had troubled us, in the actual superposition of the complete Paleozoic series.

As originally planned, the season of 1869 was intended to complete the field work of the 40th Parallel Survey. There remained of the Desert Region all the ranges from the Wasatch westward to the western edge of the Great Desert, and east of the Wasatch the western end of the Uinta Range and a portion of the Tertiary Basin of Green River were included within our field of work, an extent of country 125 miles long in an east and west direction and with a normal width of 102 miles north and south or 12,750 square miles. To cover this area required the utmost diligence and careful allotment of the time from May to November, in which alone field work was possible at that latitude and elevation. Three weeks were all that could be allotted for the topographic and geological reconnaissance of the whole Wasatch range south of the latitude of Salt Lake City, which fell to the lot of my party. It can readily be conceived that under such relations of time to area many phenomena would necessarily be but imperfectly observed. As regards the completeness of the geological column, expectations were more than realized. It was found that not only was the entire Paleozoic section completely developed but representatives of two series of pre-Cambrian formations and of a remarkably full suite of Mesozoic and Tertiary formations were exposed in this range. In the field, therefore, attention was mainly devoted to the working out of the columnar section, and it was not until many years afterwards, when, by the completion of the topographic maps, it was made possible to represent their relations graphically, that the true import of some of the great structural problems involved could be fully appreciated.

I have gone somewhat at length into these preliminary observations because the purpose of this paper being to acknowledge that an important mistake was made in the course of the work, it seems no more than justice to those that carried it on —more particularly to our deceased chief, Clarence King, to whose genius and energy was due the conception and carrying out of this great work and who personally drew all its most important conclusions—that geologists of the present day should have a realizing sense of the conditions under which it was carried on. During the nearly thirty years that have elapsed since its conception, I have had opportunities of verifying the work in many parts of the field in the light of the more complete knowledge of later times, and it has always

been a matter of wonder to me that so few mistakes were made.

The problem which had the most important bearing upon the earlier history of the Wasatch Range proved to be that with regard to the age of the Little Cottonwood granite. This is a huge, homogeneous body, somewhat in the shape of a half dome, which forms the mass of Lone Peak and the lower two-thirds of Twin Peak, and is well exposed in the deep glacial trough of Little Cottonwood Canyon that runs in a nearly straight west line between the two. Around this mass and in general dipping away from it on the north, east, and south wrap the series of Paleozoic sediments, which curve in strike from northwest on the north through north-south to northeast on the south. The lowest member of this series consists of 12,000 feet of Cambrian beds, mainly quartzites, which alone come in contact with the Cottonwood granite body. On the west face of the granite rest a series of westerly dipping crystalline schists of assumed Archean age. These beds are unconformably overlaid by the Cambrian beds, which differ from them nearly 90° both in strike and dip. That the granite was intruded into and hence later than these Archean beds is readily evident, the contacts lying along the valley slope of the range, where they can easily be seen. The contacts of the granite with the Cambrian beds, on the other hand, are less easy of access, being mostly high up on the steep mountain slopes and covered by brush and talus, so that in the time allotted for exploring this region few were actually observed. Two alternative solutions of the problem presented themselves, which are indicated by Mr. King* as follows:

"It is very evident that the granite is either an intrusive mass or else an original boss on which the sedimentary material was deposited." The close lithological resemblance of this granite to the Jurassic granites of the Sierra Nevada had at first suggested its later intrusion, but after careful weighing of all the evidence it was concluded that the preponderance was in favor of its pre-Cambrian origin. The Clayton Peak mass farther eastward, at the head of Big Cottonwood Canyon, though separated at the surface by several thousand feet of easterly dipping quartzites and limestones, and of somewhat different structure, was assumed to be part of the same boss. This assumption necessitated in Mr. King's reconstruction of the Archean surface, on which the Paleozoic sediments were deposited, the existence in this part of the original range of a steep cliff of about 30,000 feet elevation.

While there is abundant evidence in other parts of the 40th Parallel region to support Mr. King's statement that the pre-

* 40th Parallel Reports, vol. i, "Systematic Geology," p. 48.

Cambrian topography must have been of far bolder type than that of the present day, the existence of this 30,000 foot cliff has been regarded by geologists with some incredulity.

As the result of a brief personal visit to the region, Professor (now Sir) Archibald Geikie published a criticism* of Mr. King's views, based largely upon improbability of the existence of a cliff of such enormous dimensions, and concludes that the intrusion must be of post-Carboniferous age. Later in his text-book of geology he quotes this occurrence as "shown to be of post-Carboniferous age."†

A reply to Professor Geikie's criticism, on the part of Mr. King and myself, has awaited the opportunity of making a further study of the region which should be conducted with sufficiently greater thoroughness than either of the previous examinations to settle the question once for all. In consequence, however, of the extreme ruggedness of the region and the difficulty of access by most of the contact lines, lying as they do along the edges of precipitous mountain summits, such an examination would require several weeks' work with a camping party and the opportunity of making it has hitherto not presented itself. In Chapter VI of my report on the "Geology of Leadville," however, in discussing the extent of the absorbability of sedimentary rocks by eruptive masses, I took occasion to refer to one of the arguments that had influenced us in arriving at the conclusion that the Little Cottonwood granite was pre-Cambrian. This was, briefly, that the other assumption, namely, that it was later than the Cambrian quartzites that rested upon it, involved the absorption of some 500 cubic miles of these quartzites by the intrusive magma which ought to have resulted in making the magma unusually acid, whereas in point of fact, the Cottonwood granite has only 71·78 per cent of silica, which is but normal and not a specially acid type. I also referred to the fact that no included fragments of Cambrian quartzites had thus far been found in granite, although along the Archean contact, near the mouth of the canyon, such included fragments are of frequent occurrence. On the other hand, I did not mention the fact that occasional pebbles of granite had been found in the quartzite, for the reason that we had not yet observed marginal zones of basal conglomerates, such as Professor Geikie very justly observed ought to be found at the base of such slopes of land.

Van Hise‡ examined the canyon in 1889 and found granite pebbles in the Cambrian quartzite which he, however, regarded as lithologically unlike the Cottonwood granite. He considered the Cottonwood and Clayton Peak granites as identical

* This Journal (3) xi, p. 363. †Edition of 1882, p. 646.
‡U. S. Geological Survey, Bull. 86, p. 294, 297.

in character and found the limestones in contact with the latter exceedingly metamorphosed. He does not, however, appear to have found any evidence of intrusive nature at the actual contact of the Cottonwood granite body with the Cambrian quartzite. In reviewing the published evidence on the subject, he is more inclined to favor the view favored by Geikie than that of the 40th Parallel geologists, though he admits that he does not regard the objections to the latter view of so insuperable a nature as did Geikie.

In the past few seasons several pieces of Survey work have been carried on under my supervision in this portion of Utah, and I have taken advantage of the opportunity of having younger legs than my own at my disposal to have the more inaccessible portions of the granite contact along Littlewood Canyon more closely investigated.

Already in the summer of 1900, at the close of his field work in Bingham Canyon, Mr. J. M. Boutwell at my request examined the contact of granite and quartzite on the south face of the Twin Peak ridge, a few miles below Alta, and found several apophyses of granite cutting into the quartzite beds above the contact. Mr. Boutwell courteously refrained from publishing the results of his examination until I should have an opportunity of personally examining the contact. This occurred during the past summer, when Mr. Boutwell's party was making a survey of the Park City district, within a few days' ride of this locality, and the object of this paper is to state the result of this examination.

That the Cottonwood granite body is intrusive in the Cambrian quartzite is proved by the existence of apophyses of the former running across the bedding of the latter for some distance and in one observed instance spreading out again between the beds in a considerable body.

On the other hand, no metamorphism of the contact could be distinguished megascopically, and in the canyon bottom the upper surface of the granite is smooth and even, conforming with the bedding planes of quartzite, while small, rounded pebbles of a granitoid rock are found in the bed of quartzite immediately above the contact. At the mouth of the canyon the western contact of the granite body with the Archean schists is much more distinctly intrusive, being very ragged and uneven, while fragments of the former, both large and small, are included within the granite.

For a distance of over a mile above the eastern contact of the granite, quartzites and limestones, dipping steeply eastward, occupy the bed and sweep up on either wall of the canyon, thus separating the Cottonwood from the Clayton Peak eruptive body by an estimated thickness of two to three thousand feet of sedimentary beds.

The outcrop of the Clayton Peak body occupies the divide between the heads of Little and Big Cottonwood canyons, the basin at the head of the latter canyon, and the mass of Clayton Peak which forms its eastern rim; it also extends for some distance east of the latter peak in the plateau-like basin at the head of Little Snake River, where its outcrops are obscured by surface accumulation.

In my original visit to the head of Big Cottonwood Canyon, in 1869, I collected a specimen of crystalline garnet rock which presented something of a schistose structure and was thought to belong to the Archean complex. At that time the results of the studies of contact metamorphism by Doelter and others in the Predazzo-Thal and other classic localities in Europe had not been published, and even to Prof. Zirkel, who examined the specimen microscopically, the suggestion did not present itself that this was probably a phase of contact alteration of limestone. At the present day, however, when the original dense forest-covering has been cleared away and prospectors have sunk holes wherever the contact of limestone and granite is exposed, these contacts are readily observed and show conclusive evidence of the later intrusion of the granite into limestone in the abundant development of contact minerals, such as vesuvianite, garnet, etc., and of contact deposits of ores of the metals, in which the association of magnetite with pyrite, chalcopyrite, galena, etc., is most common. Marmorization of the limestone is abundant in the region and by no means confined to the contact belt, but, as Mr. King observes, spreads out over large areas in the limestone beds that have no definite relation to any known outcrop of eruptive rock.

The prevailing rock of the Clayton Peak rock is a granular diorite of the same general mineralogical composition as the Cottonwood granite, but of finer grain and apparently carrying less quartz and a greater proportion of basic silicates. The western portion of this body on the divide between Big and Little Cottonwood canyons, however, is of somewhat coarser grain and resembles the granodiorites of the Sierra Nevada. A small body exposed in Big Cottonwood Canyon, about two miles below the bend and in the same general geological horizon as the Clayton Peak mass, but some four miles north of the outcrop of the Cottonwood granite, is of the fine-grained dioritic type characteristic of the Clayton Peak mass.

Each of the diorite body of the Clayton Peak, the eastern spurs of the Wasatch Mountains, are made up of Paleozoic beds cut through quite irregularly by stocks and dikes of eruptive rocks of distinctly porphyritic structure, though of the

same general mineralogical composition as the diorite. These general relations are shown in the accompanying profile of the range on a general east and west line running through Twin Peak, the head of Little Cottonwood Canyon, and Clayton Peak.

1

A broad depression between the eastern foothills of the Wasatch Mountains and the western flanks of the Uinta Mountains is largely covered by andesitic lavas, overlying bedded tuffs of an undoubted extrusive nature, which are of Tertiary (probably post-Eocene) age. These rocks have a striking resemblance in their mineralogical composition to the diorites and porphyries of the Clayton Peak mass.

While, therefore, it must be admitted that the geological history of the region, as traced by the geologists of the 40th Parallel, is not entirely correct, it is yet too early to state exactly how far and in what way it should be modified. This must await a thorough resurvey of the region based on large scale maps, a work which has already been inaugurated by the geologists of the Survey; inasmuch, however, as it will probably be several years before this work will be sufficiently far advanced to afford final solutions of some of the most critical problems, it may be permitted to state what these problems are and to present some alternative hypothesis as to their probable solution. It is certainly a most striking fact that these several eruptive bodies, which apparently are of sufficiently similar mineralogical and chemical composition to have originated in the same general magma, occur along the line running a little north of east, which, if extended westward, would pass through the mining district of Bingham Canyon where occur the most important intrusions of porphyritic eruptive rocks in the Oquirrh Mountains, and where there have also been outpourings of later extrusives of consanguineous character along the flanks of the range. The same line, extended still farther westward to the parallel range of the Aqui Mountains, passes through a small body of extrusive, andesitic lavas and tuffs on the east flanks of that range, which, so far as known, is the only point where eruptive rocks are found in it. Attention was called to this fact in my original description of the geology of this region,* and also to the fact that along this line in the

* 40th Parallel Report, vol. ii, Descriptive Geology, p. 459.

Oquirrh and Wasatch Mountains there has been the greatest concentration of ore deposits. This generalization holds good at the present day, but modern developments show that there is an evident genetic connection with the older eruptives, while none is apparent with the extrusive flows.

The further statement in my original report,* that in the Wasatch range the mineral deposits are mostly concentrated within a radius of 6 or 7 miles around Clayton Peak, also holds good in the light of present developments, which, moreover, point to a more intimate genetic relation of ore deposition to the Clayton Peak than to the Cottonwood body, for as far as known no ore deposits have been found on the contact of the latter with the surrounding rocks, whereas they are most common around the Clayton Peak mass. It must be noted, however, that these deposits occur for the most part in calcareous rocks, and no calcareous rocks are known to occur in contact with the Cottonwood granite. It may be assumed that the Cottonwood granite, if regarded as a distinct body, did not reach a higher horizon than a thousand feet or more below the top of the Cambrian quartzite. That the Cottonwood and Clayton Peak granite beds were part of the same mass and hence of contemporaneous origin, was a plausible assumption as made by the 40th Parallel geologists but one which has not yet been supported by the finding of any connection between the two on the surface. In the absence of such connection a possible alternative hypothesis is that there have been successive eruptions in this region from the same general magma, each of which reached a higher geological horizon than the preceding one. On this hypothesis it may be assumed that the Cottonwood batholith was intruded while the Cambrian beds were still resting undisturbed upon the upturned edges of the Archean, and that it did not reach the top of the Cambrian; that this eruption was followed later by the mountain-building movement which threw the Paleozoic beds into anticlinal and synclinal folds, and that after they were thus upturned, the Clayton Peak mass intruded into the Carboniferous limestone and produced the well recognized contact phenomena now seen. The stocks or dikes of porphyry in the somewhat higher geological horizons to the eastward might have been contemporaneous or slightly later eruptions from the same general magma, and have owed their less completely crystalline structure to the differing conditions under which they consolidated. The abundant mineralization in the region has evidently been in part a direct and in part an indirect result of this phase of activity.

As regards the extrusive flows in the depression between the Wasatch and Uinta Mountains, they rest on a surface from

* Ibid, p. 364.

which not only Mesozoic but a great thickness of Eocene Tertiary beds must have been denuded, hence a long period must have elapsed between the older eruptions and this one, which, by analogy with the regions to the westward, may be assumed to have occurred during the Miocene period.

It has been assumed as a result of the 40th Parallel work—an assumption that has not yet been seriously modified by later investigations—that while there was in the Cordilleran region toward the close of the Carboniferous a general elevation of the Great Basin region accompanied by greater or less erosion, the main mountain-building movement occurred at the close of the Jurassic. In the Wasatch some evidence of a transgression at this period was found by the 40th Parallel geologists, but it was not insisted on in their reports because without a reëxamination of the field it could not be considered absolutely conclusive. It would now appear probable that the eruption of the Clayton Peak mass must have been contemporaneous with or closely followed this Jurassic movement. If future investigations prove that the Cottonwood body is of the same age as the Clayton Peak mass, there will be found exposed here in unusual detail the contact phenomena of an enormous granitic batholith, extending in horizon from the Archean across a vertical column of 25 to 30,000 feet of sedimentary beds of varying composition, and an opportunity will be afforded to study what influence, if any, has been exerted on the intrusive magma by the rocks through which it passed and which, presumably, must have been absorbed by it.

U. S. Geological Survey, Washington, D. C.

Art. XIV.—*A Contribution to a List of the Fauna of the Stafford Limestone of New York;* by Mignon Talbot.

The Stafford limestone, as stated by Dr. J. M. Clarke,* is the western of the two comparatively persistent limestones of the Marcellus shale of New York, and extends from a point near Phelps, Ontario County, to Lake Erie. Several outcrops have been recorded and studied. These may be found along Flint Creek and near Baggerly Corners in Ontario County; at Littleville and at another spot near Avon, in Livingston County; at Stafford, Leroy, and Batavia, in Genesee County; and at Wende, at Lancaster, and near Buffalo,† in Erie County. Borings from various salt shafts show its presence at York, Livonia, and the outlet of Conesus Lake, in Livingston County, and Miss Elvira Wood‡ reports it from a sewer excavation in Buffalo.

Three small collections of this limestone, one from Batavia and two from Leroy, N. Y., have been worked out in the paleontological laboratory of the Yale University Museum, and a number of species not previously reported from this horizon has been found, sufficient to warrant the publication of a list supplemental to those given by Dr. Clarke and Miss Wood.

In Miss Wood's account of the section at Lancaster, the lowest bed of the limestone is described as made up largely of *Strophalosia truncata* and *Ambocœlia nana*. This same rock, together with typical Stafford material, is in the collection from Batavia, about forty miles to the east of Lancaster. Without visiting the section, it would be unwise to attempt to interpret the occurrence of this bed at Batavia, as, unfortunately, its exact horizon was not reported. Of the two collections from Leroy, only ten miles farther east, neither contains this rock.

In studying the Batavia and Leroy material in the Yale University Museum, comparison with the lists as given from the typical Stafford limestone and including the lower beds of the Lancaster section resulted in the following:—

	Number of species previously reported.	Species from Batavia and Leroy not heretofore recorded.
Anthozoa	7	4
Crinoidea	1	
Bryozoa	4	2
Brachiopoda	38	5

* Bull. 49, N. Y. St. Mus., pp. 115-138, 1901.
† 15th Ann. Rept. N. Y. St. Geol., 1895, pt. i, p. 316.
‡ Bull. 49, N. Y. St. Mus., pp. 139-181, 1901.

	Number of species previously reported.	Species from Batavia and Leroy not heretofore recorded.
Pelecypoda	10	9
Gastropoda	14	8
Pteropoda	3	
Cephalopoda	11	5
Crustacea	7	1
Annelida	1	
Total	96	34

From this comparison it will be seen that an addition of thirty-five per cent has been made to the known fauna of the Stafford limestone. All of the additional species in the appended list, except the Anthozoa, one of the Cephalopoda, and four of the Gastropoda, are typical Hamilton species.

Supplemental Faunal List from the Stafford Limestone.

	Batavia.	Leroy.
Anthozoa.		
Amplexus, sp. undet.		×
Cystiphyllum, sp. undet.		×
Syringopora, sp. undet.		×
Zaphrentis, sp. undet.		×
Bryozoa.		
Stictopora sinuosa Hall	×	×
Trematopora immersa Hall		×
Brachiopoda.		
Cranæna Romingeri Hall	×	×
Lingula ligea Hall	×	
Liorhynchus, sp. undet.	×	×
Spirifer macronotus Hall	×	
S. Marcyi Hall	×	
Pelecypoda.		
Aviculopecten insignis Hall	×	
Grammysia Eriopia Hall		×
Macrodon Hamiltoniæ Hall		×
Modiomorpha subalata Hall	×	×
Nucula corbuliformis Hall		×
Palæoneilo constricta Hall		×
Panenka, sp. undet.	×	×
Sphenotus arcæformis Hall		×
Sphenotus, sp. undet.		×

	Batavia.	Leroy.
Gastropoda.		
Bellerophon, cf. *brevilineatus* Conrad		×
B. curvilineatus Conrad*		×
B. Leda Hall		×
Euomphalus planodiscus Hall		×
Platyceras carinatum Hall	×	×
P. erectum Hall	×	×
Platyostoma lineatum Conrad		×
Pleurotomaria Ella Hall	×	×
Cephalopoda.		
Gomphoceras lunatum Hall	×	
Goniatites discoideus Hall	×	×
Nautilus acræus Hall		×
Orthoceras Thestor Hall	×	×
Orthoceras, sp. undet.		×
Crustacea.		
Cyphaspis ornata, var. *baccata* Hall		×
Total	15	29

Paleontological Laboratory, Yale University Museum,
April, 1903.

* *Bellerophon curvilineatus* Conrad has not been reported above the Upper Helderberg limestone, and at that horizon has been found only in the eastern part of the State, at Schoharie and in the Helderbergs.

Art. XV.—*On the Formula of Bornite;* by B. J. Harrington.

The subject of the formula of bornite is one which has long required investigation. If we refer to the standard works on mineralogy we generally find that the formula of the *crystallized* mineral is given as Cu_5FeS_4 (or $3Cu_2S{\cdot}Fe_2S_3$ as originally written by Plattner) and that numerous analyses of the *massive* mineral from various parts of the world show little agreement with this formula and often differ widely from one another. The difference in the composition of the massive specimens has been explained by saying that they were mixtures of bornite with chalcopyrite and chalcocite, and no doubt in the case of some analyses these or other mixtures have been called upon to do duty for bornite.

So far as the writer is aware, crystallized bornite has not been met with in Canada. The massive mineral of evident purity, however, occurs at many localities, and it was thought that an examination of carefully selected specimens might throw some light on the question under consideration. Those chosen were from widely separated points in the Provinces of Quebec, Ontario, and British Columbia, and the results of their analysis are as follows:

	I.	II.	III.	IV.	V.
Copper	63·55	62·78	62·73	63·34	63·18
Iron	10·92	11·28	11·05	10·83	11·28
Sulphur	25·63	25·39	25·79	25·54	24·88
Insoluble	----	0·30	----	0·38	0·24
	100·10	99·75	99·57	100·09	99·58
Sp. gr. at 15°C	5·085	5·055	5·090	5·029*	----

I. Harvey Hill, P. Q.
II. Bruce Mines, Ontario.
III. Dean Channel, How Sound, B. C.
IV. Copper Mountain, South Fork of Similkameen River, B. C.
V. Texada Island, B. C. The two last analyses were made by Mr. J. E. A. Egleson.

It will be observed that the results agree well with one another and also with the formula Cu_5FeS_4, which gives:

	Cu_5FeS_4
Copper	63·27
Iron	11·18
Sulphur	25·55
	100·00

* The fragment used for this determination contained a little malachite, the effect of which would be to lower the specific gravity slightly.

Nor are such concordant results likely to have been obtained from mere mixtures of different sulphides. Furthermore, they are in close accord with a number of previously published analyses of massive bornites. Out of fifty analyses cited by Hintze* about one-fifth agree well with the formula Cu_5FeS_4 and the average of eight of these gives:

Copper	62·85
Iron	11·57
Sulphur	25·34
	99·76

We pass now to the consideration of crystallized bornite. Through the kindness of Professors Dana and Penfield of Yale University, the writer has been able to obtain a specimen of the crystallized mineral from Bristol, Connecticut, which, though long known, had apparently never been analyzed.† It came from the Brush collection (specimen No. 805) and though partly massive showed at one end a group of fairly distinct rhombic dodecahedrons, which, so far as could be ascertained microscopically, were entirely free from other minerals and were found to have a specific gravity of 5·072 at 15° C. Their analysis gave:

		Cu_5FeS_4
Copper	63·24	63·27
Iron	11·20	11·18
Sulphur	25·54	25·55
	99·98	100·00

Here then we have a *crystallized* bornite which does not agree in composition with the commonly accepted formula Cu_5FeS_4. As to this formula, which has so long been assigned to the crystallized mineral, we find that it was based upon the analysis of a Cornish specimen published by Plattner in 1839.‡ This was followed in the same year by an analysis of another Cornish specimen by Varrentrapp,§ while a third analysis by Chodney appeared in the same journal in 1844.‖ These three analyses, together with two others, also of Cornish specimens, are given below:

* Handbuch der Mineralogie, 1901, p. 915.

† For an analysis of the massive mineral from Bristol see Dana, "System of Mineralogy," 1892, p. 77.

‡ Pogg. Ann. xlvii, p. 351, 1839.

§ Ibid., p. 372.

‖ Ibid., lxi, p. 395, 1844.

	I.	II.	III.	IV.	V.	Cu_5FeS_4
Copper.....	56·76	58·20	57·89	57·71	57·68	55·58
Iron	14·84	14·85	14·94	13·89	15·11	16·36
Sulphur	28·24	26·98	26·84	27·17	26·46	28·06
	99·84	100·03	99·67	98·77	99·25	100·00

I. Condorra Mine, Cornwall. Analysis by Plattner.
II. No locality is given, but the description makes it practically certain that the specimen was from Cornwall. Analysis by Varrentrapp.
III. Redruth, Cornwall. Analysis by Chodney.
IV. and V. Cornwall. Exact locality not known. Analyses by the writer.

It is obvious that none of these analyses agrees well with the formula Cu_5FeS_4, nor could it be expected that satisfactory results would be obtained from the analysis of the Cornish crystals, all of which, so far as the writer has had an opportunity of observing, are very impure.* Not only have they generally been altered by oxidation, but they almost always contain a yellow sulphide with the characters of chalcopyrite. In some specimens nearly every crystal when broken shows a yellow nucleus of chalcopyrite and the writer found it impossible to obtain material which could be regarded as pure. The early analysts, too, evidently found difficulty, if we are to judge from their descriptions. Plattner, for example, tells how he broke up the crystals and picked out the pieces which he considered to be free from copper pyrites. He further trusted to washing with distilled water in order "as far as possible" to remove the superficial portion of the crystals which appeared to be somewhat oxidized. Varrentrapp, again, states that the small cubical crystals examined by him all contained a nucleus (kern) of chalcopyrite and had their surfaces covered with a layer of copper oxide. He admits also that his results do not agree well with those of Plattner.

There is then good reason for believing that the formula Cu_5FeS_4 was deduced from analyses of impure material, and, as we have seen, it does not apply to the crystallized mineral as found at Bristol, Connecticut. If a mineral having this formula really exists, then we have two distinct species—bornite and something else. Artificial products agreeing well with the formula Cu_5FeS_4 are said to have been prepared,† and there

* Professor Penfield has kindly sent me a number of crystals broken from specimens of Cornish bornite in the Brush collection and these are also very impure.

† See Hintze, "Handbuch der Mineralogie," 1901, p. 914.
Doelter states that by heating a mixture of CuO,Cu_2O and Fe_2O_3 in a current of H_2S at a temperature not above 200° he obtained the "normal bornite $Cu_2S+CuS+FeS$" in aggregates of little cubes. He, however, gives no analysis of these (Zeitschr. f. Kryst., xi, 1886, 36).

is no evident reason why such a mineral should not occur in nature.

Many of the published analyses of so-called bornite show a composition which could be easily explained by the presence of chalcopyrite, which would reduce the proportion of copper and increase the proportions of iron and sulphur. In other cases chalcocite would appear to be present. In this connection it is interesting to note that a mixture of one molecule of bornite with one of chalcopyrite would give the old formula, thus:

Bornite	Cu_4FeS_4
Chalcopyrite	$CuFeS_2$
	$Cu_6Fe_2S_6 = 2Cu_3FeS_3$.

Such a mixture would contain 73·20 per cent of bornite and 26·8 per cent of chalcopyrite.

The range for the specific gravity of bornite is sometimes stated to be 4·9 to 5·4; but a substance with as definite a composition as pure bornite evidently possesses should not show so great variation, and it will probably be found that when the material is carefully selected the range will be more like 5·05 to 5·10. As we have seen, the crystallized mineral from Bristol gave 5·072.

Department of Chemistry and Mineralogy,
McGill University, May, 1903.

Art. XVI.—*The Iodometric Determination of Gold in Dilute Solution;* by Ralph N. Maxson.

[Contributions from the Kent Chemical Laboratory of Yale University—CXVII.]

In a former paper from this laboratory* it was shown that under suitable conditions potassium iodide acts normally upon auric chloride according to the equation

$$3KI + AuCl_3 = 3KCl + AuI + I_2$$

and it appeared that this reaction may serve as the basis of a trustworthy method for the determination of small quantities of gold,—the freed iodine being estimated by careful bleaching with sodium thiosulphate and the final addition of standard iodine to the incipient coloration of the starch indicator, rose in most cases, or only blue at the outset when the starch has not undergone hydrolytic change.† Three series of experiments were made upon solutions of auric chloride standardized by the ferrous sulphate method and by the method of Vanino,‡ and one series upon auric chloride made from pure gold foil.

In the first series the solutions of auric chloride (0·8710 grm. to the liter) sodium thiosulphate nearly $\left(\frac{N}{100}\right)$, and iodine nearly $\left(\frac{N}{100}\right)$ were of such strength that an inaccuracy of 0·01$^{cm^3}$ in measurement would correspond to about 0·000009 grm. for the gold solution and to a little more than 0·00001 grm. in terms of gold for each of the other solutions. It is hardly to be supposed that individual readings can uniformly approximate the truth within 0·01$^{cm^3}$, and as there are six readings to be made in every complete determination, the chances for inaccuracy amounting to several hundredths of a milligram of gold, dependent to a great extent as to direction and amount upon the personal equation of the operator, are considerable. Should all these reasonable errors chance to lie in the same direction, the cumulative errors are likely to reach at least ± 0·00005 grm., and may be even more.

The actual error, due to all causes, found in the first series of twelve determinations, excepting a single determination manifestly not in line with the others, and tending to make the average error smaller, amounted in the mean to − 0·00005 grm. of gold between extremes of +0·00003 and − 0·00010 grm.

In the second series of twenty experiments, in which the solution of gold was ten times as dilute as in the experiments

* Gooch and Morley, this Journal, viii, 261 (1899).
† Hale, this Journal, xiii, 379 (1902).
‡ Ber. Dtsch. Chem. Ges., xxxi, 1763.

of the first series, the other solutions being of the original strength, the total average error actually observed was considerably lower, as would be expected, and amounted to +0·00002 grm. of gold between extremes of +0·00006 grm. and −0·00002 grm.

In a third series of ten experiments, in which the dilute gold solution (0·0871 to 1 liter) was used, nearly $\frac{N}{1000}$ iodine and nearly $\frac{N}{1000}$ thiosulphate were employed. The average error amounted to less than 0·000004 grm. between extremes of +0·000020 grm. and −0·000029 grm., but in these determinations the sensitiveness of the starch indicator to iodine becomes an important factor, and it was necessary to introduce a correction of 0·1$^{cm^3}$ for the amount of the $\frac{N}{1000}$ iodine necessary to bring out the starch reaction in the volume of liquid used, when tested in blank.

In still another series of fourteen experiments, made upon a gold solution (0·0104 to 200$^{cm^3}$) prepared by dissolving pure gold foil in chlorine water and destroying the free chlorine by ammonia, the average error amounted to +0·000002 grm. between extremes of +0·00001 grm. and −0·000008 grm.

The results of these experiments may be summarized as follows:

	Number of determinations.	Gold taken.	Strength of solutions.			Error. Average.	Extremes.
			Iodine	Thiosulphate	Gold		
Series I	11	8·71^{mg} to 4·35^{mg}	$\frac{N}{100}$	$\frac{N}{100}$	0·871	−0·05^{mg}	+0·03^{mg} / −0·1^{mg}
Series II	20	0·87^{mg} to 0·087^{mg}	$\frac{N}{100}$	$\frac{N}{100}$	0·0871	+0·02^{mg}	+0·06^{mg} / −0·02^{mg}
Series III	10	0·871^{mg} to 0·087^{mg}	$\frac{N}{1000}$	$\frac{N}{1000}$	0·0871	+0·004^{mg}	+0·020^{mg} / −0·029^{mg}
Series IV	14	0·520^{mg} to 0·052^{mg}	$\frac{N}{1000}$	$\frac{N}{1000}$	0·052	+0·002^{mg}	+0·01^{mg} / −0·008^{mg}

It is plain that the average experimental errors, due to all causes, do not very much exceed the errors which might naturally be expected to arise from errors of reading. In repeating the work of Gooch and Morley I have obtained results of a reasonably similar order of accuracy. The process has, however, been recently criticized unfavorably by Rupp* on the

* Ber. Dtsch. Chem. Ges., xxxv, 2011.

ground that the *percentage errors* are found to be large. It is to be noted, however, that large percentage errors are inevitable, in the application of volumetric methods to the determination of total weights measured in hundredths of a milligram, or tenths of a milligram, or even in a few milligrams, inasmuch as the reasonable errors to be expected in the measuring of solutions strong enough to be visibly reactive are of themselves large when reckoned as percentages of small absolute amounts. These errors, small as they are, Rupp attributes to the secondary reactions of potassium iodide on aurous iodide, in which gold is reduced and iodine set free. I have been unable, however, to find evidence of such action under the conditions of experimentation during periods much longer than those required for the completion of the analytical process. Thus aurous iodide, obtained by treating a solution of auric chloride containing 0·0125 grm. of gold, with potassium iodide according to the directions of Gooch and Morley, adding starch and bleaching the starch with sodium thiosulphate, gave no color of starch blue after the interval of an hour. A second similar experiment gave the same result. Inasmuch as an interval of ten minutes is enough for the complete manipulation of a single determination, it is plain that the stability of the aurous iodide does not figure in the accuracy of the determination of the small amounts of gold for which the process was designed.

As a substitute for the method described by Gooch and Morley and sustained by the fifty-five analytical determinations mentioned, Rupp announces a process for the estimation of gold depending upon the precipitation of that element from auric chloride by means of standard arsenious acid in excess, according to the equation

$$3As_2O_3 + 4AuCl_3 + 6H_2O = 3As_2O_5 + 12HCl + 4Au,$$

and the titration of the excess of arsenious acid by iodine. To show the reliability of the process Rupp cites six determinations, in one of which the titrations were made in two portions. Four of these six deal with $61{\cdot}2^{mg}$ of gold each, while in two the gold amounted to $6{\cdot}1^{mg}$. These figures, which cover the entire range of the amounts used in Rupp's analytical determinations, do not represent the order of magnitude or range of the amounts of gold handled by Gooch and Morley, which varied from $8{\cdot}7^{mg}$ to $0{\cdot}052^{mg}$. Only two determinations upon amounts comparable with those used by Gooch and Morley were made, and in only these two were suitably dilute solutions of iodine $\left(\frac{N}{100}\right)$ and of arsenious acid $\left(\frac{N}{100}\right)$ employed.

The gold solution employed in all the determinations was of such strength that a single error of $0{\cdot}01^{cm^3}$ in reading would

amount to an error of 0·00006 grm. of gold: while the arsenious acid employed in three determinations was so strong $\left(\frac{N}{2}\right)$ that an inaccuracy in reading to the extent of 0·01$^{cm^3}$ would introduce an error of 0·0003 grm., actually greater than the whole amount of gold involved in each of the individual determinations of the greater part of the entire series of Gooch and Morley, and nearly six times greater than their minimum amounts. It is plain, therefore, that Rupp's experiments do not relate to the small amounts of gold handled by Gooch and Morley, and that experiments made with such solutions as Rupp employed cannot form a basis upon which to found a method for the determination of the very small amounts of gold determined by Gooch and Morley.

It has seemed to be desirable, therefore, to submit the process of Rupp to further investigation. In these experiments the procedure of Rupp was followed in general, but the reagents were all used in solutions reasonably dilute, as must be the case if accuracy is to be attained. The gold solution used was prepared from pure gold chloride, and was carefully standardized by means of metallic magnesium, and electrolytically with the revolving cathode, according to the method of Gooch and Medway.* The solution contained 0·0580^{g} of metal in 1 liter, and was free from nitric acid. The arsenic solution was $\frac{N}{100}$ and was made by properly diluting a standard solution of $\frac{N}{10}$ arsenious oxide. The iodine solution used was approximately $\frac{N}{100}$, and was made by properly diluting an iodine solution, which had been carefully standardized against the $\frac{N}{10}$ arsenic solution mentioned above.

In reducing and determining the gold the procedure was as follows:—A measured quantity of the slightly acid solution of standard auric chloride was drawn from a burette into a 100$^{cm^3}$ graduated flask and to this was added a measured excess of a standard solution of arsenious acid dissolved, as usual, in acid potassium carbonate. In every case the excess of the arsenious acid was considerable and the acid carbonate introduced simultaneously was enough to more than neutralize the slight acidity of the auric chloride. Rupp states that the reduction takes place in acid solution, but I have been unable to effect the precipitation of the gold when free acid is present, but from a solution made so acid that the carbonate present in the

*This Journal, xv, 320 (1903).

Exp.	Fraction titrated.	Gold found in each fraction. grm.	Gold computed for the whole solution. grm.	Gold taken. grm.	Error. grm.
I	¼	0·00010	----	----	----
	¼	0·00011	----	----	----
	¼	0·00013	----	----	----
	----	----	0.00045	0·00087	−0.00042
II	¼	0·00010	----	----	----
	¼	0·00013	----	----	----
	¼	0·00010	----	----	----
	----	----	0·00044	0·00087	−0·00043
III	¼	0·00017	----	----	----
	¼	0·00016	----	----	----
	¼	0·00014	----	----	----
	----	----	0·00063	0·00087	−0.00024
IV	¼	0·00060	----	----	----
	¼	0·00060	----	----	----
	¼	0.00062	----	----	----
	----	----	0·00242	0·00232	+0·00010
V	¼	0.00056	----	----	----
	¼	0·00058	----	----	----
	¼	0·00058	----	----	----
	----	----	0·00229	0·00232	−0·00003
VI	¼	0·00043	----	----	----
	¼	0·00043	----	----	----
	----	----	----	----	----
	----	---	0·00172	0·00232	−0·00060
VII	¼	0·00075	----	----	----
	¼	0·00074	----	----	----
	¼	0·00074	----	----	----
	----	----	0·00297	0·00232	+0·00065
VIII	¼	0·00061	----	----	----
	¼	0·00058	----	----	----
	----	----	0·00238	0.00290	−0·00052
IX	¼	0·00082	----	----	----
	¼	0·00081	----	----	----
	¼	0·00080	----	----	----
	----	----	0·00324	0·00290	+ ·00034
X	¼	0·00072	----	----	----
	¼	0·00073	----	----	----
	----	----	0·00290	0·00290	0·00000
XI	¼	0·00066	----	----	----
	¼	0·00071	----	----	----
	¼	0·00075	----	----	----
	----	----	0·00283	0·00290	−0·00007

standard arsenic is insufficient to neutralize the free acid the gold may be precipitated upon the further addition of a suitable amount of acid potassium carbonate. The flask containing the gold, the arsenite and the acid carbonate was heated thirty minutes upon a steam bath, then cooled and filled to the 100^{cm^3} mark. Measured portions of the solution, 25^{cm^3} each, were titrated with the standard iodine in presence of acid potassium carbonate and potassium iodide. The details of these experiments are shown in the accompanying table.

A comparison of the figures obtained in the individual titrations of portions of a single reduction show that the difference due to the errors of analysis are reasonably small, rarely exceeding a few units in the fifth decimal place—or a few hundredths of a milligram. The errors of the process, however, computed by comparing the average of these single determinations with amount of gold actually taken, range from $-0{\cdot}6^{mg}$ to $+0{\cdot}65^{mg}$, are wholly irregular, and are approximately ten times as large, reckoned absolutely or in percentages, as the errors obtained by Gooch and Morley when handling similar amounts of gold. So far as the evidence of these experiments goes, it is plain that the process of Rupp is wholly untrustworthy for the determination of the very small amounts of gold concerned.

I take this opportunity to thank Professor F. A. Gooch for much kindly aid and advice in the preparation of this paper.

Art. XVII.—*Radioactivity of Thorium Minerals;** by George F. Barker.

The discovery of the spontaneous radioactivity of uranium and its compounds, by Becquerel in 1896† has affected most profoundly our views not only of the constitution of matter, but also of the relations existing between matter and energy. The extraordinarily delicate means which he proposed for the detection of this radioactivity, first the photographic method, and second the electric, made possible the remarkable discovery by the Curies and Bemont in 1898‡ of the new element radium, whose quantity in uraninite is so infinitesimal as to be far beyond our power of detection by the balance, or even by the spectroscope. Indeed, only the enormous ratio of the energy of radium to the radioactive matter concerned in emitting it, enabled it to be recognized even by the electrometer.

In February, 1898, G. C. Schmidt presented to the Physical Society of Berlin§ a preliminary paper on the rays emitted by the element thorium and its compounds. This paper was printed in extenso in *Wiedemann's Annalen* in the following April.‖ On the 12th of the same month, a communication from Mme. Sklodowska Curie was presented by Lippmann to the Academie des Sciences of Paris¶ giving an account of her examination of the radioactivity of a number of substances, including the compounds of thorium. Like Schmidt, she used both the photographic and the electric methods in her investigations, making the latter quantitative. Two condenser plates were employed, 8 centimeters in diameter, separated 3 centimeters from each other, and having a potential difference of 100 volts maintained between them. A uniform layer of the substance to be examined, finely pulverized, was placed on the lower plate; and since the emitted rays ionized the air between the plates and rendered it conducting, a current traversed the condenser and charged the electrometer to which the upper plate was connected. Knowing the capacity of the electrometer, inasmuch as the speed of deviation of the needle is proportional to the current-strength, it is possible to determine the current in absolute measure. It was found preferable, however, to measure the counter potential difference required to maintain the electrometer at zero. As its charge was feeble, this compensation was accomplished by means of a piezoelec-

* Read before the National Academy of Sciences, April 22, 1903.
† Comptes Rendus, cxxii, 420, 501, 689, 1896.
‡ Comptes Rendus, cxxvii, 1215, December, 1898.
§ Verh. Phys. Ges. Berlin, xvii, 14, February, 1898.
‖ Ann. Phys. Chem., II, lxv, 141–151, April 15, 1898.
¶ Comptes Rendus, cxxvi, 1101, April 12, 1898.

tric quartz, one armature of which was connected to the upper plate. By placing weights in a scale-pan attached to the quartz plate, the difference of potential produced was so regulated as to secure compensation between the quantity of electricity traversing the condenser and that of opposite sign yielded by the quartz. With a given condenser, and a given substance, it was observed that the current increased with the difference of potential between the plates, and with the gas pressure. It also increased as the plates were separated. With high potential difference, the current tends toward a constant limit, the *saturation-current*. This saturation-current was taken as the measure of the radioactivity, the number of ions produced per second being greater in proportion as the radiation absorbed is greater.

With this apparatus, the radioactivity of uranium is measurable with considerable precision; the current having an order of magnitude of 10^{-11} ampere. It varied but little with temperature, was not affected by light, and did not seem to vary sensibly with time. The value of the current obtained with Moissan's metallic uranium (probably containing a trace of carbon) was $2{\cdot}4.10^{-11}$ amperes. Tested in this way it was found that thorium compounds were very active, thoria surpassing even metallic uranium. It was observed that the current increased with the thickness of the material, a layer 0·25 millimeter thick giving a current of $2{\cdot}2.10^{-11}$ ampere, and one of 6 millimeters one of $5{\cdot}3.10^{-11}$ ampere. Thorium sulphate gave a current of only $0{\cdot}8.10^{-11}$ ampere. The phenomenon was most regular with a layer only 0·25 millimeter thick, varying between wide limits when the thickness was 6 millimeters, especially with the oxide. Thorium rays were found to be more penetrating than those of uranium, those emitted by thoria from thick layers being more penetrating than those from thin ones.* Subsequently Owens studied the radiations from thorium compounds, determining the conditions affecting its constancy, the form of the saturation curve, the character of the radiations from different salts, the types of radiation, selective absorption, the effect on the rays of suspended particles, the variation of conductivity with air pressure and the absorption of the radiations by air.†

Inasmuch as uranium and thorium were the only elements then known possessing radioactive properties, it was natural to examine the minerals in which these substances occur, with a view to determine their properties in this regard. Accordingly Mme Curie, using the electric method and the apparatus above described, tested thirteen well-known minerals,

* Rapports au Congrès International de Physique, iii, 79, Paris, 1900.
† Phil. Mag., V, xlviii, 359, 1899.

containing both uranium and thorium. They all were found to be radioactive, though in very different degrees. Measured, as above, in terms of current, xenotime gave $0{\cdot}03.10^{-11}$ ampere, niobite 0·3, fergusonite 0·4, monazite 0·5, aeschynite 0·7, samarskite 1·1, thorite 1·4, cleveite 1·4, orangeite 2·0, autunite 2·7, chalcolite 5·2, carnotite 6·2 and pitchblende (uraninite) from 6·5 to $8{\cdot}3.10^{-11}$ ampere. The remarkable fact that four of these minerals were more active than metallic uranium and especially that the uraninite from Johanngeorgenstadt was nearly four times as active, led, as is well known, to the discovery in it of the three new radioactive substances, polonium, radium and actinium.

In February, 1902, Hofmann and Zerban published a paper on Radioactive Thorium* obtained from certain minerals allied to uraninite. In connection with Strauss, the former of these chemists had previously prepared thoria from bröggerite, cleveite and samarskite, and had found it to be radioactive. Hofmann and Zerban now observe that the activity of these thoria preparations may be materially increased by fractional precipitation with potassium sulphate or chromate, with hydrogen peroxide or with sodium thiosulphate, the most active fractions being those most readily precipitated. By using ammonium carbonate as the precipitant, on the other hand, the most active material is found in the most soluble fraction. To their surprise, however, they found that the thoria thus obtained, on keeping it for five months, even in closed vessels, lost a large part of its radioactivity. Thus the most active thoria, which in June blackened the photographic plate very strongly even through glass, acted very feebly in the following November. Electroscopic tests also confirmed this diminution in radioactivity. A specimen of thoria from bröggerite which in November discharged the electroscope in 1 minute required 3m. 45s. to do the same thing in January. A specimen from cleveite, which in November took 1m. 10s. to discharge the electroscope, required in January 2m. 5s. And a preparation from samarskite, which took 1m. 30s. in November to effect this discharge, did the same thing in January only after 1m. 50s.

These results lead the authors to assume (1) that the thoria prepared from bröggerite, cleveite and samarskite possesses, not a primary but a secondary induced activity, and (2) that this induced activity is due to the uranium always present in the minerals referred to. In proof of this assumption, the authors prepared thoria from Brazilian monazite sand, which they assert contained no trace of uranium, and found it to be absolutely inactive, whether tested by the photographic plate

* Ber. Berl. Chem. Ges., xxxv, 531, 1902.

or by the electroscope. They then rubbed one gram of this thoria with five grams of a specially purified uranoso-uranic oxide, heated the mass to 400° for four hours and allowed the mixture to stand for fourteen days. It was then dissolved in nitric acid, the thoria precipitated as oxalate, washed and ignited. On testing it, it was found to be strongly active, discharging the electroscope in 1m. 5s., even after four weeks.

In the course of some experiments on the photographic action of radioactive substances made in December, 1899, I obtained an intense darkening of the plate after an exposure of 8 hours, with uranyl chloride, uranium chloride, metallic uranium and uraninite, the darkening being in the order named. A few weeks later, using uraninite as the radioactive source, with an exposure of 16 hours, I observed that the penetrating power of the rays it emitted, through metal plates ·0025 inch in thickness, were in the order aluminum, tin, copper, silver, lead, platinum. Similar experiments with de Haen's radium salts, brought from Europe in September of that year, showed much more powerful action, an exposure of fifteen minutes giving a distinct effect upon the plate.

During the past winter these experiments have been resumed, with especial reference to the compounds of thorium and the minerals containing it. To compare the intensity of these radioactive minerals, an exposure of 48 hours was made with uraninite (from Bohemia and from Saxony), gummite (North Carolina), autunite (Limoges), euxenite (Norway), thorite (Norway), samarskite (North Carolina), and orangite (Norway). While the intensity of the darkening was in general in the order above given, the effect of the first three minerals far exceeded any of the others. Moreover the penetrating power of the emitted rays was examined at the same time by placing each of the minerals upon a thin brass stencil plate, having its initial cut through it. The rays from gummite seemed to penetrate the brass the most readily; then followed the uraninite, the autunite, the euxenite, the samarskite and the thorite.

The investigations were then continued with especial reference to the mineral monazite, the chief source of the thoria now so largely used in this country and Europe, for the manufacture of the Welsbach gas mantles. By the courtesy of Mr. M. C. Whitaker, of the Chemical Department of the Welsbach Company, I was furnished with authentic samples of Brazilian monazite sand, of monazite sand from North Carolina and of pure thoria from each of these; this thoria having been obtained in the course of analysis. I also obtained a sample of pure ammonium-thorium nitrate and one of thorium oxalate. On exposing these six substances on a sensitive photographic plate thoroughly protected from the light, for 48 hours, satis-

factory impressions were obtained from all of them. Of the two monazites, that from Brazil gave perhaps a trifle the darker stain; that specimen containing 90 per cent of monazite and about 6 per cent of thoria, while the North Carolina sand contained about 66 per cent of monazite and 4 per cent of thoria. For purposes of comparison a piece of metallic uranium was exposed under the same conditions upon the same plate.* The darkening effect was very considerably greater than that produced by the thoria.

In view of the assertions of Hofmann and Zerban already stated, to the effect, first, that Brazilian monazite sand contains no uranium, and second, that in consequence of this, the thoria obtained from this source is not radioactive, the above described experiments were carefully repeated. The results obtained were practically the same. The plate was darkened, during an exposure of 48 hours, by all the six substances placed upon it; by the two monazite sands from Brazil and from North Carolina, by the two thorium oxides obtained from these, by the ammonium-thorium nitrate and by the thorium oxalate. The oxalate stain was perhaps a little darker than the nitrate and the Brazilian stain a trifle darker than the North Carolina one. Apparently, therefore, the second of Hofmann and Zerban's conclusions, to wit: that thoria prepared from Brazilian monazite sand is "absolutely inactive," can hardly be accepted as final.

The claim, however, that the radioactivity of thorium compounds is not a primary but a secondary induced activity due to the presence of uranium in the minerals in which it occurs, needs to be considered here. The monazite sands are complex and variable in composition, and may in isolated cases contain even uranium. The specimens used in the experiments above described therefore were submitted to several competent chemists, all of whom reported that they were entirely free from this element. The main conclusion would therefore seem legitimate, that radioactive thorium compounds may be prepared from minerals which do not contain uranium. If so, the conclusion can hardly be evaded that thorium is a primary radioactive substance.

The composite character of the rays emitted by radioactive substances appears to have been observed about the same time by Becquerel,† by the Curies‡ and by Giesel.§ According to Becquerel‖ these rays are of three sorts: (1) those deviable

* Given me in 1899 in Moissan's Laboratory, by the courtesy of Professor Lebeau.

† Comptes Rendus, cxxix, 1205; cxxx, 206, 372; cxxxii, 371.

‡ Comptes Rendus, cxxix, 996; cxxx, 73, 76, 647; cxxxii, 133.

§ Ann. Phys. Chem., II, lxix, 834, 1899.

‖ Proc. Roy. Inst., xvii, 1, March 1902.

by a magnetic field, which are apparently identical with cathode rays; (2) those not so deviable, but very readily absorbed; and (3) non-deviable rays, which like Röntgen rays have great penetrating power. He states that the rays emitted by uranium are substantially of the first kind, those from polonium are of the second kind, and those sent out by radium and thorium consist of all three kinds. In subsequent investigations, Rutherford,* in connection first with Grier† and afterward with Soddy,‡ made this classification more rigid. Radium rays were divided into three distinct types; α rays, easily absorbed by thin layers of matter, and producing the greater part of the ionizing effect; β rays, consisting of negatively charged particles moving with high velocity and similar in all respects to cathode rays; and γ rays, non-deviable in a magnetic field and of a very penetrating character. The energy radiated in the form of α rays is about 1000 times greater than that emitted as β rays. During the present year Rutherford§ has succeeded in obtaining the deviation of the α rays both in the magnetic and the electric fields, and has thereby proved these rays to consist of positively charged material particles having a much greater mass and a lower velocity than those constituting the β rays. In fact the mass of those particles is of the same order as that of the hydrogen atom and they travel with a speed only about one-tenth that of light. Moreover, it has been shown‖ that the α rays contribute by far the greater part of the electrical effect, while the β rays produce practically all of the photographic effect. Thus uranium when freed from UrX, though inactive to the photographic plate, possesses a nearly normal activity when examined by the electric method.

In his investigations upon thorium, Baskerville says:¶ "The oxide (sp. gr. 9·25) obtained from the insoluble citrate affects the sensitive plate in the dark after an exposure of seventy-two hours but slightly, while the oxides of higher specific gravity are quite active. A number of plates have been exposed using oxides obtained through the research, monazite sand from which the thorium salts were prepared, uranium nitrate, acetate, uraninite and blanks for comparison. The radioactivity increased with increase in specific gravity." Hearing that he had finally obtained a thoria so pure that it did not affect the photographic plate, I wrote him asking for the loan of a small sample to compare with my own specimens. In the letter accompanying the specimen which he was good enough to send me, he says: "I have secured pre-

* Phil. Mag. VI, v, 177, 1903.
† Phil. Mag. VI, iv, 315, 1902.
‡ Phil. Mag. VI, v, 445, 1903.
§ Rutherford, l. c.
‖ Phil. Mag. VI, v, 441, 1903.
¶ J. Am. Chem. Soc., xxiii, 761, 1901.

parations which did not affect a sensitive photographic plate noticeably after an exposure of seventy hours." He prefers, however, the electric method, and says: "I have prepared a large number of thorium preparations, several hundred, and have not yet succeeded in securing a thorium compound or derivative which did not possess some radioactivity by the latter method." Upon testing the "*very* pure" specimen received, by an exposure of 96 hours, a satisfactory darkening of the photographic film resulted; though much less intense than the stain given by the thoria previously employed. Were it possible to separate by fractionation or otherwise a sample of thoria into two portions, one of which had only a photographic and the other only an electric action, it might suggest that the constituent of the thoria which emits the β rays may be separable from the one emitting the α rays. Inasmuch as all the thoria preparations examined by Baskerville were obtained from monazite sand, coming either from North Carolina or Brazil, and inasmuch as none of these preparations failed to show a radioactivity either photographic or electric, the conviction is strengthened that thorium does not owe its activity to an induction from uranium existing in the minerals from which it was obtained.

The fact that inactive substances acquire under the influence of radium a temporary activity was first observed by the Curies,* who called the effect "la radioactivite induite." On exposing a disc of zinc for example, 8^{cm} in diameter, opposite a surface of radium 4^{cm} in diameter and 3^{cm} distant, an activity 2000 times that of uranium was obtained; practically the same results being obtained with nickel, brass, bismuth, aluminum and lead. Solutions of radium salts appear to produce the phenomenon with more intensity than the solid salts. Gases even may in this way be made radioactive. Water distilled from radium solutions is radioactive. When barium sulphate is precipitated from a solution of barium chloride by sulphuric acid in presence of a salt of uranium, it is found to be radioactive. Debierne,† proceeding in this way and using actinium in place of uranium, obtained a barium salt of great activity, which could be concentrated by fractionation, the most active fractions being 1000 times as active as uranium. The result was a radioactive barium, carrying its properties into all its salts and distinguished from radium mainly by its spectrum and by the gradual loss of its properties.

The discovery in 1899, almost simultaneously by the Curies‡ and by Rutherford,§ of the emission by both radium and

* Comptes Rendus, cxxix, 714, 1899; cxxx, 1013, 1900.
† Comptes Rendus, cxxxi, 333, 1900.
‡ Rapports au Congrès Intern. de Physique, iii, 79, 1900.
§ Phil. Mag., V, xlix, 2, 1900; VI, v, 95, 1903.

thorium, of a gas or vapor itself temporarily radioactive and capable of emitting rays, has thrown much light upon this so-called induced radioactivity. This "emanation," as Rutherford calls it, diffuses without change through gases and liquids, and even porous substances, but not through glass or mica. It is chemically inert, and may be passed through ignited platinum black and lead chromate without change. It appears to be a new member of the argon family, with an atomic mass between forty and one hundred. The emanations from thorium and radium differ somewhat in properties, that from the former liquefying at —120° and that from radium at —150°. Moreover, the radioactivity of the thorium emanation rapidly decays, falling to half its value in one minute; while that of the radium emanation retains its active properties for several weeks. On the other hand, the "excited" radioactivity, as Rutherford prefers to call it, produced by the former emanation, is much more permanent than that produced by the latter. Since excited radioactivity can be produced on bodies if the emanation be present, even in the absence of a radioactive substance, and since the amount of effect is directly proportional to the amount of the emanation, it follows, first, that the production of excited radioactivity is a property of the emanation and therefore is always produced on bodies when the radioactive emanations from thorium and radium are present; and second, that uranium and polonium which do not give off any emanation, do not possess the power of exciting radioactivity. In the present view of science, therefore, it would not seem probable that the radioactivity of thorium is a secondary or excited radioactivity due to the uranium associated with it in the minerals above mentioned.

Art. XVIII.—*Significance of Silicic Acid in Waters of Mountain Streams;* by W. P. Headden.

While engaged in some work on the waters of the San Luis Valley I was struck by the unusually high percentage of silicic acid, from 25 to upwards of 40 per cent, in the residues obtained on evaporation. I was, at the time, inclined to attribute this to some accident, or perhaps error. The water had been shipped in jugs, and this may have had some influence, but several conditions lead me to believe that this influence, if any at all, was wholly negligible. The water was evaporated as soon as possible after it was received at the laboratory, so that the water was in these jugs but a few days—from seven to ten at the longest. The quality and character of the residue did not support this view, and the action of the water on the jugs may be left out of consideration.

The waters to which reference is here made were of excellent quality and were either artesian or spring waters, but I also observed that the water of the Rio Grande del Norte, at Del Norte, was richer in silicic acid than is usual for river waters, and richer here than further down the stream. There was nothing in the composition of the dissolved mineral matter apparently worthy of special attention except it be the high percentage of silicic acid, and while this was common to several waters from different sources, I did not feel that this characteristic was sufficiently well established to entitle it to acceptance. We gained but little that at the time would bear any interpretation, beyond the fact that the spring and artesian waters of this large basin are of exceptionally good quality. This statement does not apply to a subordinate basin in which the towns of Mosca and Garrison, formerly called Hooper, are situated. The wells of this basin at a depth of 500 to 880 feet yield a brown water rich in alkalies, but relatively and as a rule absolutely poorer in silicic acid than the artesian waters.

There are a number of springs along the eastern margin of the valley and some larger ones in the southern part of it, the waters of which are of good quality and carry from 5·3 grains to 17·6 grains of mineral matter to the imperial gallon, of which silicic acid constitutes as much as 30 per cent.

This line of work was laid aside in order to take up others which seemed more urgent and perhaps more important also, but recently, while studying the changes suffered by river waters used for the purposes of irrigation, my attention has again been called to the presence of silicic acid as a characteristic mineral constituent of the waters of mountain streams

whose collecting grounds are granitic areas and whose courses have not yet traversed a long enough reach of open country, or the plains, to have received either water from collecting areas of a different character or drain waters from lands adjacent to their courses.

I shall now set forth such facts as have fallen under my observation which seem to me to amount to reasonable proof that this high percentage of silicic acid, varying greatly within the limits of 15 and 46 per cent, is, in the instances which I have studied, specifically due to the action of water and carbon dioxid, and, perhaps, also of the acid products arising from the decomposition of vegetable matter on the felspars of the granite of the region. The action of the organic matter on the felspars is, in the first phase of their decomposition, at the very utmost insignificant if not nil, such, at least, is the result obtained by an experiment made to ascertain how great a part is played by such agents. In passing I will mention, apropos to the presence of organic matter, the fact, that on evaporating a large quantity of water from our mountain streams, from the Cache a la Poudre for instance, one obtains at last a solution which is strongly colored by humus-like substances and possesses an extremely disagreeable odor. In the case of the Cache a la Poudre water used there was no question of pollution by sewage, for in all the distance traversed by its waters from their several sources to the point where the sample was taken, a distance of about sixty miles, the total population does not exceed 150 souls, and the number of cattle grazing in this district is so small that the question of pollution arising from either of these sources is absent, and would be even if the flow of the river were very small, but this seldom falls as low as 200 second feet and is usually much greater—still this water, when larger quantities of it are evaporated down, shows the presence of a significant amount of organic matter which, despite its odor suggestive of an animal origin, I feel justified in assuming to come from decaying vegetable matter. I shall subsequently set forth the facts on which I base the statement that this organic matter plays no important role in determining the amount and character of the mineral matter dissolved out of the rock and carried in solution in such river waters.

The amount of silicic acid usually carried by river waters is small, the maximum shown in the analyses of forty-five European river waters being 21 per cent of the total solids, the Rhine at Strassburg, which carried in the sample analyzed 16·1 grains mineral matter per gallon—but this sample seems to have been an exception even for the Rhine, for other samples of its water show much smaller quantities of substances in solution and materially lower percentages of silicic acid; at Basle for instance,

the water carried 11·8 grains of mineral matter in each imperial gallon, 1 per cent of which was silicic acid; at Bonn it carried 11·9 grains, 5 per cent of which was silicic acid; at Arnheim, 11·1 grains, of which 6 per cent was silicic acid. The Rhone, sample taken near Geneva, yielded 13 grains total solids to the imperial gallon, of which 8·2 per cent was silicic acid; this, 8·2 per cent, is, with the exception of the 21 per cent for the sample of Rhine water taken at Strassburg, the maximum shown by the forty-five European rivers.

Spring waters as a rule carry still smaller amounts of silicic acid than the river waters. Thirty-two analyses given in Watts Chem. Dict., Art. Water, show 17 and 22 as maximum percentages, the total solids being 7·3 and 4·3 grains respectively. Analyses of twenty-nine artesian waters show 3 per cent as the maximum quantity of silicic acid present in their mineral matter, which in this sample equalled 36·7 grains per gallon.

Mineral springs sometimes show larger percentages of silicic acid in their mineral constituents, but even these, the springs of the Yellowstone National Park and one or two others, geysers, excepted, show maxima of 18 and 23 for the percentages of silicic acid in their total solids. This statement is based on the analyses of 179 American and 66 foreign mineral springs.

I deem these data sufficient to justify the assertion that silicic acid usually constitutes a comparatively small percentage of the total solids contained in the waters of fresh and mineral springs as well as of those contained in river waters.

The lake and oceanic waters, particularly the latter, have suffered such varied and deep changes in regard to the composition of their mineral content that the silicic acid has either been entirely removed or its quantity has been reduced to a mere trace; the maximum that I can find given is 0·05 per cent of the total solids present. It is usually absent.

The water of the springs of the Yellowstone National Park, and of a few others, contains silicic acid in very notable quantities. Such springs frequently, if not always, have an elevated temperature. This, however, is not the case with the springs and wells referred to; and the rivers, as is well known, have a low temperature, their waters being cooled by the melting of snow accumulated within the areas of their drainage. The presence of silicic acid in the waters of the former class of springs is attributed to the action of heated water aided by pressure and the presence of alkalies. The heat in these cases is of volcanic origin, a residual volcanic effect, while the alkalies are supposed to be obtained from the alteration of the various kinds of felspars, one or more of which is present in most kinds of rocks, especially in volcanic rocks. Such theories are in no manner

applicable to the river waters of our mountains and it is very doubtful whether they would apply at all to any of the springs occurring in the San Luis Valley. It is true that eruptive rocks occur in the southern part of the valley; it is also true that some of the springs mentioned later are located on the northern edge of this belt of lava occurrences. I do not, however, believe that the presence of silicic acid in the waters is influenced by the lava which occurs here as remnants of a sheet which formerly covered the country, especially to the southward, but whose point of eruption was probably quite remote. If these waters do come in contact with eruptives of any sort in their course to the surface, they are cold and the waters would act upon them as they would if they were on the surface plus whatever effect the pressure, molecular or other, under which the water exists in the rocks may produce. These springs are bringing no subterranean heat to the surface, the temperatures observed being 59° F. and 70° F. There are warm and hot springs south and southwest of this, but they are many miles away and the water is relatively poor in silicic acid; that of Ojo Caliente, temperature 122° F. contains about 75 grains total solids per imperial gallon, of which less than one per cent is silicic acid. The range of the temperature of the artesian wells throughout the valley is from 53° F. to 71° F. It seems then that the part played by heat in taking the silicic acid into solution in these cases is as good as nothing, while in the case of the rivers receiving their supply directly from fields of melting snow it is patently out of the question. All the statements that I recall relative to the source of silicic acid occurring in waters derive it principally from the felspars, to which I think no serious objection can properly be taken. The contexts as well as the examples given lead one to infer that it is derived from the felspars of eruptive rocks. Such a supposition would not be admissible in this instance. The waters, especially of the rivers, are surface waters, the volume of which in the summer season varies regularly with the periods of sunshine and darkness, twelve hours of greater and twelve hours of lesser flow, corresponding to day and night. Their flow in autumn and winter is greatly diminished owing to the retention of the surface waters in the form of snow and ice. There are no large springs nor any considerable number of small ones except such as are supplied by the soil-covered valleys of the mountains and whose waters are likewise surface waters. There is comparatively a very small amount of igneous rock occurring in their various drainage areas.

In the case of the Cache a la Poudre there are a few porphyry dikes and one inconsiderable body of lava within its drainage area. These observations are not applicable to the

Rio Grande del Norte in the same measure as to the Poudre and other streams mentioned in this paper. In these cases we cannot assign the presence of the silicic acid in the waters to the causes usually cited as explaining it, and I do not believe that it is necessary that we should even in other cases.

In regard to the San Luis Valley it should be explained that there is a bed of volcanic ash, bombs and even a sheet of lava at or near Antonito, of no great northward extension, this place being apparently at its northern limit, and it is doubtful whether the silicic acid in the artesian well waters is derived from felspars of volcanic origin, either in the form of ash or lava, as the wells are driven through the clays, shales, and sands deposited in the bed of the lake formerly filling the valley. If any doubt were entertained of the origin of these strata, the fish vertebræ, shells and fragments of wood found in them would dispel it. The most striking character of the sands is the presence of kidney-shaped concretions of calcic carbonate, having a smooth exterior coating. Some of them are filled with a cellular mass, others are composed of concentric layers of calcic carbonate which, like the exterior one when scaled off from the interior mass, is, owing to its extreme thinness and smoothness, somewhat translucent. The other grains making up these sands are fragments of granite, some of them even showing particles of pyrites, quartz both light and dark, and grains of felspar. There may be some grains of eruptive rocks, but I am not fully enough convinced of this to assert their presence.

The granites of the respective areas are the metamorphic granites of this region, many of them closely resembling the Pike's Peak type, others identical with them.

The residue obtained by evaporating the water of the Rio Grande del Norte, sample taken near the town of Del Norte, contained 27·15 per cent of silicic acid; that from an artesian well in the town of Alamosa, Spriesterbach's Well, 27·0 per cent; from a large spring in the southern or rather southeastern portion of the valley, McIntyre's Spring, 29·64 per cent; from the McNieland Well 36 per cent; and that from the Bucher Well 46·9 per cent of silicic acid.

The conditions under which these waters occur preclude the application of the theory advanced to explain the presence of silicic acid in the waters of geysers and hot springs in general. The maximum temperature observed in any of the springs or wells in the San Luis Valley was 71° F. and the minimum 53° F. These waters do not issue from, and probably do not, in any portion of their course, pass through eruptive rocks of any sort, except it be as surface waters in the lava cappings prevalent to the west of this valley. The river and artesian waters probably

have a common source, the melting snows on the peaks of the Sangre de Cristo range on the east and on those of the San Juan country on the west. The percentage of silicic acid in the total solids, however, is as great as that in the residues obtained from any of the geysers or other hot springs in the world. The highest percentages that I have found for the latter are: for the Great Geyser of Iceland 42 per cent, calculated of course on the total mineral matter held in solution; for the Coral Springs in the Yellowstone National Park 32 per cent; for the Hot Spring, Garland, Arkansas, 23 per cent; for the White Terrace Geyser, New Zealand, 22 per cent; and for the Calistoga Spring in California, 18 per cent. These examples suffice to show the relative richness of the Rio Grande del Norte water and that of the springs and artesian wells of the San Luis Valley in silicic acid.

It is perfectly plain that the absolute amount of silica carried by the waters is not given by the statement of the percentage of this substance in the total solids, but will depend upon this latter, or the total amount of mineral matter held in solution. In this respect, too, some of the spring and well waters carry more significant quantities than one would expect.*

The Great Geyser of Iceland carries 86·1; the Coral Spring, Yellowstone National Park, 133·7; White Terrace Geyser, New Zealand, 185·5; and the Hot Spring, Arkansas, 5·0 grains in each imperial gallon. The Rio Grande del Norte at Del Norte carried 6·2; Dexter's Spring 13·7; McIntyre's Spring 12·8; McNieland's Well 17·4; the Bucher Well 15·8; and Spriesterbach's Well 28 grains.

I considered the high percentages of silica in the total solids of these waters as anomalous until a study of the waters of the Cache a la Poudre and some neighboring streams led me to change my view and to consider it as normal in the case of such waters, and to attribute the absence of silicic acid from ordinary waters to the character of the drainage area, the character of the rocks through which the waters pass before they rise as springs or artesian waters, and to changes suffered during the course of their flow.

The following analyses were made of residues obtained by evaporating the samples to dryness; both copper and porcelain vessels were used without appreciable difference in the results. The residues were dried at temperatures varying from 180° to 200° C. The ignition is put in brackets to designate that it is

*I have reduced my data to the common basis of grains to the imperial gallon because my own results have been calculated on this basis, and further because grains per imperial gallon are easily converted into parts per thousand or million according as one may prefer.

by difference, but an ignition was made in each instance to assure myself that the ignition given is correct within reasonably close limits.

The first analysis of Cache a la Poudre water given is of a sample taken above the mouth of the North Fork, on Oct. 3, 1902. This point was chosen because there are no tributaries entering above this point whose waters are not wholly gathered within and run for their whole course over an area whose surface rocks are the metamorphic granites and schists of the region. The sample was taken at a time when the water was perfectly representative of the drainage water of this area.

The analysis resulted as follows:

Analysis of Cache a la Poudre Water, Sample taken above the Mouth of the North Fork.

Analytical results.	Per cent.	Grs. Imp. Gal.	Combined.	Per cent.	Grs. Imp. Gal.
SiO_2	20·871	0·6053	$CaSO_4$	11·782	0·3417
SO_3	6·928	0·1946	$CaCO_3$	24·781	0·7186
CO_2	20·790	0·6029	$MgCO_3$	9·063	0·2628
Cl	3·575	0·1037	K_2CO_3	4·325	0·1254
Na_2O	12·931	0·3750	Na_2CO_3	9·146	0·2652
K_2O	2·949	0·0855	NaCl	5·899	0·1711
CaO	18·741	0·5238	Na_2SiO_3	8·772	0·2544
SrO	trace	trace	Fe_2O_3, Al_2O_3	0·388	0·0113
MgO	4·336	0·1257	Mn_3O_4	0·063	0·0018
Fe_2O_3, Al_2O_3	0·388	0·0113	Ignition	(9·233)	0·2678
Mn_3O_4	0·063	0·0018			
Ignition	(9·233)	0·2678	Sum	83·452	
			Excess of SiO_2	16·546	0·4798
Sum	100·805				
O equiv. to Cl	·805		Total	99·908	2·8999
Total	100·000	2·8974			

Total solids 2·9 grs. per imp. gal.

The second sample of which I shall give an analysis was taken July 30, 1902, on which date the river was carrying about double its usual flow for this season. The flow had been 300 second feet for the preceding fortnight, to which it fell again within a few days, but at the time the sample was taken the flow was 600 second feet. In this analysis I did not test for either strontia or lithia.

Analysis of Cache a la Poudre Water, Sample taken 150 feet above Headgate of Larimer Co. Ditch.

Analytical results.	Per cent.	Grs. Imp. Gal.	Combined.	Per cent.	Grs. Imp. Gal.
SiO_2	20·542	0·5341	$CaSO_4$	8·420	0·2198
SO_3	4·951	0·1287	$CaCO_3$	36·431	0·9471
CO_2	21·626	0·5622	$MgCO_3$	10·758	0·2797
Cl	7·619	0·1980	NaCl	12·573	0·3276
Na_2O	8·874	0·2307	K_2SiO_3	5·391	0·1402
K_2O	3·286	0·0854	Na_2SiO_3	4·342	0·1129
CaO	23·884	0·6209	Fe_2O_3, Al_2O_3	0·894	0·0232
MgO	5·147	0·1338	Mn_3O_4	0·093	0·0024
Fe_2O_3, Al_2O_3	0·894	0·0232	Ignition	(4·802)	0·1248
Mn_3O_4	0·093	0·0024			
Ignition	(4·802)	0·1248	Sum	83·704	
			Excess of SiO_2	16·296	0·4237
Sum	101·718	2·6443			
O equiv. to Cl	1·718	0·0446	Total	100·000	2·6005
Total	100·000	2·5997			

Total solids 2·6 grs. per imp. gal.

The sample of water from Boulder Creek was taken from a tap in the town of Boulder which is supplied with water taken from the creek at a point where the water is perfectly representative, being gathered wholly within a granitic area. The analysis follows:

Analysis of Water from Boulder Creek, Sample taken from a tap in the town of Boulder.

Analytical results.	Per cent.	Grs. Imp. Gal.	Combined.	Per cent.	Grs. Imp. Gal.
SiO_2	21·985	0·6156	$CaSO_4$	14·124	0·3955
SO_3	8·305	0·2325	$CaCO_3$	31·317	0·8769
CO_2	17·037	0·4770	$SrCO_3$	0·235	0·0066
Cl	7·425	0·2079	$MnCO_3$	6·143	0·1720
Na_2O	6·870	0·1924	$MgCl_2$	4·305	0·1205
K_2O	2·720	0·0762	KCl	4·304	0·1205
Li_2O	trace	trace	NaCl	3·586	0·1004
CaO	23·373	0·6544	Na_2SiO_3	9·818	0·2749
SrO	0·165	0·0046	Fe_2O_3, Al_2O_3	1·098	0·0307
MgO	4·760	0·1313	MnO	0·341	0·0095
Fe_2O_3, Al_2O_3	1·098	0·0307	ZnO	trace	
MnO	0·340	0·0095	Ignition	(7·607)	0·2130
ZnO	trace	trace			
Ignition	(7·607)	0·2130	Sum	82·878	2·3205
			Excess of SiO_2	17·144	·4789
Sum	101·676	2·8451			
O equiv. to Cl	1·676	0·0469	Total	100·022	2·7994
Total	100·000	2·7982			

Total solids 2·8 grs. per imp. gal.

The waters of Clear Creek are less representative than the others, not because their gathering grounds are different or that they have their courses through territories of different geological formations, for such is not the case, but there is a very much larger population within its area of drainage, the towns of Central City, Black Hawk, Idaho Springs, Georgetown, and some smaller towns being within it and above the point where the sample was taken, which was from the Welch Ditch a mile above the town of Golden. Further, mining and particularly milling is actively carried on within its drainage area and on its branches. The tailings of twenty odd mills are discharged into its waters, to say nothing of the mine water which daily mingles with that of the creek. The effect of these conditions is plainly shown in the analysis but does not obscure the true character of the water to any extent. I will not abridge the analysis, though parts of it are superfluous for the present purpose.

Analysis of Water from Clear Creek, Sample taken from Welch Ditch, one mile above Golden.

Analytical results.	Per cent.	Grs. Imp. Gal.	Combined.	Per cent.	Grs. Imp. Gal.
SiO_2	17·953	1·3644	$CaSO_4$	42·252	3·2111
SO_3	24·844	1·8881	$CaCO_3$	6·483	0·4927
CO_2	6·870	0·5221	$MnCO_3$	7·707	0·5856
Cl	2·479	0·1884	$MgCl_2$	0·764	0·0581
Na_2O	7·073	0·5375	KCl	4·017	0·3053
K_2O	3·506	0·2665	K_2SiO_3	1·578	0·1196
Li_2O	trace	trace	Na_2SiO_3	13·952	1·0604
CaO	21·041	1·5991	Al_2O_3	2·477	0·1883
SrO	trace	trace	Fe_2O_3	1·916	0·1450
MgO	4·011	0·3048	ZnO	0·207	0·0157
ZnO	0·207	0·0157	CuO	trace	trace
Al_2O_3	2·477	0·1883	PbO	none	none
Fe_2O_3	1·916	0·1456	Mn_3O_4	0·691	0·0525
Mn_3O_4	0·691	0·0525	Ignition	(7·491)	0·5693
CuO	trace	trace			
PbO	none	none	Sum	89·535	6·8036
Ignition	(7·491)	0·5693	Excess of SiO_2	10·464	·7953
Sum	100·559	7·6423	Total	99·999	7·5989
O equiv. to Cl	·559	·0425			
Total	100·000	7·5998			

Total solids 7·6 grs. imp. gal.

It will be observed that the lowest percentage of silicic acid in these residues is 17·9 and the highest 22, while the intermediate ones are about 21 per cent. In an analysis made of Poudre water in 1897, I obtained upwards of 36 per cent of silica. My attention was attracted by the general agreement of these analyses, especially by the fact that three of them agree in showing almost the same excess of silica after having combined all of the bases. This is in strong contrast to the residues obtained by the evaporation of ground waters, drainage waters, or river waters taken in the lower portion of their courses which, especially in the case of the Cache a la Poudre, consist very largely, and at times wholly, of return waters, i. e. such as have been taken from the river, have been used for irrigating purposes, and have found their way back again. The residues from such waters frequently show an excess of bases over the quantity necessary to saturate the inorganic acids. The excess of acids in these analyses is so pronounced that there is no question about its being actually the case. The same is shown by the analyses of the geyser waters and those of the hot springs previously alluded to. There can be no question raised about the silicic acid having been in solution for the waters were perfectly clear, but as a matter of precaution were filtered before being evaporated to dryness, and there is no difference in the results whether the evaporation was conducted in copper or porcelain vessels.

The difference between these waters as mountain streams and when they have become plains streams suggests that the difference observed may be a characteristic of mountain streams, whose waters have not come in contact with any other rocks than granites, gneisses or schists. This suggested that an examination of water from a greater depth might add interesting information. I accordingly obtained a sample of water from the Running Lode mine at a depth of 825 feet. The water is clear and of good quality. The vein at this point is tight and there are no ore bodies immediately above this point along which the water has to move. The country rock is that characteristic of Gilpin County, varying from a schist to a compact granite. The hanging wall in this instance is frequently composed of a white orthoclase. The vein matter is highly silicified but there is not much kaolin, though there is a little scattered through the ore. The residue from this water gave the following results:

Analysis of Water from the Running Lode Mine.

Analytical results.	Per cent.	Combined.	Per cent.
SiO_2	11·298	$CaSO_4$	39·835
SO_3	23·423	$CaCO_3$	13·610
CO_2	16·099	$MgCO_3$	13·724
Cl	1·936	K_2CO_3	2·433
Na_2O	8·262	Na_2CO_3	5·276
K_2O	1·659	NaCl	3·195
Li_2O	trace	Na_2SiO_3	6·861
CaO	24·039	Fe_2O_3, Al_2O_3	0·102
SrO	trace	Mn_3O_4	0·120
MgO	6·563	Ignition	(6·935)
Fe_2O_3, Al_2O_3	·102		
Mn_3O_4	·120	Sum	92·091
Ignition	(6·935)	Excess of SiO_2	7·915
Sum	100·436	Total	100·006
O=Cl	·436		
Total	100·000		

Total solids 23·0 grs. per imp. gal.

On combining the results of this analysis we find here as in the other cases a decided excess of acids which can scarcely be supposed to be due to other than free silicic acid.

The uniformity of these results indicate that these waters are entirely normal for the conditions under which they occur, i. e. within or in contact with granite or rocks rich in felspar. In this case the rocks do not belong to the eruptives, but I cannot see why the class of rock in which the felspar might occur should make any material difference in the general result. The composition of the residues might be considered as suggesting a lime mineral other than felspar as having furnished the mineral matter to the waters, but local conditions make it very probable, and direct experiment will, I think, establish it, that the felspars do in these cases furnish the mineral matter to these waters. I do not by any means intend to claim that the felspars are the only minerals acted on by water and carbon dioxid, but simply that our waters represent the products of such action and it is evident that neither high temperature nor great pressure have played any part in producing the solutions. These two factors have been appealed to to account for the excessive silicic acid in the geysers and hot springs, but my results indicate that these are not necessary to account for the presence of the silicic acid. These points seem to me to have been well tested in some experiments which I have made with

finely powdered felspar. The object of the experiment was to discover the line of decomposition suffered by this mineral under ordinary conditions and at or near the surface of the rock masses. In passing I will state that my observation upon the effect of the presence of sodic carbonate, in so far as the conditions of observation are applicable, is that it does not increase the amount of silicic acid present. This fact may be due to the removal of the silicic acid by precipitation; be this as it may, the alkaline waters of our foot hills are always poor in silicic acid even though they percolate through a sand rich in felspar. I notice too that the geysers in the Yellowstone National Park richest in silicic acid have an acid reaction.

The experiments with felspar were conducted as follows: In the first experiment felspar was placed in a gallon aspirator, and treated with distilled water in separate portions, each portion remaining in contact with the felspar 48 hours. In order to keep the powdered felspar agitated a current of air was caused to pass through it continuously, and to still further imitate the actual conditions, a small amount of carbonic acid (CO_2) was mixed with the air. This was continued until nearly 35 gallons of water were collected, which was evaporated to dryness in platinum dishes. I feared to heat the residue above the temperature of boiling water before analyzing it. I would have evaporated it at a lower temperature had it been feasible for me to do so, for it can scarcely be doubted but that some of the CO_2 besides that which was probably present as bicarbonates, was expelled during the continued boiling. The residue, as I analyzed it, was as nearly representative of the solution as I could make it.

The amount that went into solution in this experiment was equal to 1·6 grains per gallon. The maximum quantity that I succeeded in getting into solution was 4·536 grains per imperial gallon, in which case I treated the pulverized felspar with a saturated solution of CO_2 for 16½ days. The solution of CO_2 was put on the felspar and the bottle sealed. The whole was shaken very frequently, on an average three times hourly during the day. This sample of felspar was pulverized in an agate mortar to avoid bringing any iron into the solution, as water charged with CO_2 dissolves finely powdered iron quite readily. The distilled water used in all of the experiments had been freshly distilled and left no residue on evaporation. The action of the water upon the glass of the containing vessels has been assumed to have been so small as to be negligible.

The felspar used was a flesh-colored orthoclase from a point of the mountains locally known as the Horsetooth. It was such as is characteristic of the granites of this range. The sample analyzed was perfectly fresh and resulted as follows:

Analysis of Felspar used in Experiments.

SiO_2	65·760
SO_3	0·003
P_2O_5	0·040
Cl*	
Al_2O_3	19·291
Fe_2O_3	trace
CaO	0·314
SrO	trace
BaO	none
MgO	0·029
Mn_3O_4	0·061
K_2O	11·592
Na_2O	2·728
Li_2O	trace
	99·818

The residue obtained from the first experiment with this felspar showed the following composition:

Analysis of Residue—First Experiment with Felspar.

Analytical results.	Per cent.	Combined.	Per cent.
SiO_2	40·724	$CaSO_4$	16·801
SO_3†	9·879	$CaCO_3$	5·921
CO_2	5·473	$MgCO_3$	1·611
Cl	3·170	K_2CO_3	6·380
Al_2O_3	2·704	KCl	6·667
Fe_2O_3	0·311	K_2SiO_3	3·950
CaO	10·241	Na_2SiO_3	10·354
SrO	trace	Al_2O_3	2·704
MgO	0·771	Fe_2O_3	0·311
K_2O	10·972	SrO	trace
Na_2O	5·249	Li_2O	trace
Li_2O	trace	Ignition	16·366
Ignition	16·366		
Sum	105·860	Sum	71·065
Less $CO_2+O=Cl$	6·187	Excess of SiO_2	34·075
			105·140
Total	99·673	Less CO_2 expelled	5·473
		Total	99·667

* The chlorin was not tested for in the felspar, but the aqueous extract shows it abundantly, and as the P_2O_5 probably exists as apatite the presence of some chlorin would be accounted for if it were a chloro-apatite. Fluorin was not tested for.

† The SO_3 and Cl were not determined in this residue. These determinations are taken from the other residues.

Without discussing the probable combinations which actually existed in solution, it is evident that an unduly large amount of silica had been taken up. The result presented by this analysis represents the action of rain or snow water under ordinary conditions. The carbonic acid introduced was moderate in quantity and was thoroughly mixed with the air before being drawn through the water. Both the carbon dioxid and air were well washed; this was done to prevent the introduction of organic matter, chlorin or other impurity with the air.

The second experiment was conducted differently. A quantity of felspar was powdered, passed through a 100 mesh sieve and treated with water saturated with CO_2, without any attempt to remove the iron derived from the buckboard by means of the magnet or otherwise. The containing vessels were sealed and allowed to stand for twenty-two days with frequent shaking. When the vessels were unsealed some of them showed a little pressure. As the iron derived from the buckboard had very largely gone into solution, I passed a current of air through the vessels before I filtered off the felspar—this was a mistake. The iron was easily oxidized and precipitated. It required only about forty-five minutes for the oxidation to become apparent to the eye, but the air current was continued for forty hours when the whole was filtered and evaporated in platinum vessels, the same precautions being taken as in the previous case. The analysis of this residue resulted as follows:

Analysis of Residue—Second Experiment with Felspar.

Analytical results.	Per cent.	Combined.	Per cent.
SiO_2	14·353	$CaSO_4$	16·806
SO_3	9·879	$CaCO_3$	29·432
CO_2	19·874	$MgCO_3$	4·013
P_2O_5	0·381	KCl	6·668
Cl	3·170	K_2CO_3	10·367
Al_2O_3	1·119	Na_2CO_3	3·736
Fe_2O_3	0·136	Na_3PO_4	1·257
CaO	23·412	Na_2SiO_3	6·765
SrO	heavy trace	Al_2O_3	1·119
MgO	1·919	Fe_2O_3	0·136
K_2O	11·279	Ignition	5·464
Na_2O	6·491	Excess of SiO_2	11·018
Li_2O	trace		
Ignition	25·337	Total	96·783
Sum	117·370		
Less $CO_2+O=Cl$	20·588		
Total	96·782		

I stated above that it was a mistake not to have filtered off the felspar before precipitating the iron oxid, for had I done so I could have determined how much silica, if any, was carried down with the oxid, but as it is we have an imitation of what takes place in all river and spring waters where ferrous salts occur, i. e. oxidation and precipitation of the ferric hydrate. The analysis is too low when we subtract the whole of the carbonic acid and oxygen equivalent to the chlorin found. There is no doubt but that the most if not all of the CO_2 was expelled upon ignition. I have found it to be almost completely expelled even when there was not enough silicic acid to account for it, and there is no means of judging how much was left in this residue, if any, so I have subtracted the whole of it. If the analysis were really badly made and the missing 3·3 per cent were all sodic oxid, which is by no means the case, there would still be a very considerable excess of acids.

The general resemblance of these results except in the relative quantities of potassic and sodic oxids is striking, the more so as they agree with one another and are unlike ordinary river waters.

The experiments with the felspar and the character of the mine water show that they are such as are normally produced by the action of water and carbonic acid upon this mineral without the aid of higher temperatures or pressures.

These experiments further indicate the course and character of the action of water upon felspar—i. e. it attacks those molecules containing calcium and sodium, possibly existing as molecules of labradorite and albite, more readily than those containing potassium—further that the silicic acid is dissolved as such by a process of hydration and exists in the solution as free silicic acid or as a very complex or condensed acid: the former seems much more probable.

These facts, if they be accepted as such, account for the character of the Rio Grande water, it being just such a water as the local conditions would account for. The spring and well waters are simply the same water—i. e. water running into the valley from the mountain streams and sinking into the lower strata, which are composed of sands derived from the breaking down of the rocks composing the adjacent mountains containing an abundance of felspar, and are not mixed with other water or subjected to conditions which cause radical changes in their dissolved mineral matter.

These facts easily account for the silicification of vein matter and the deposition of chalcedonic quartz, etc. in veins and elsewhere. The possible influence of organic acids, especially at the surface, has been suggested because it is so often mentioned. I had an aqueous solution of humic acids and some precipitated and washed humus; a quantity of felspar was treated

with distilled water just as in the experiments described with the addition of a liberal quantity of these; the results agreed well with those obtained with water and CO_2 alone after deducting the fixed residue contained in the humus; the duration of this experiment was twenty-two days. I am not prepared to state that such acids play no part in the decomposition of rocks, but the result of this experiment indicates that they play a less important part than the statements frequently met with would indicate, and which, furthermore, the composition of the ash obtained by incinerating them would also suggest.

A remarkable feature in the result of these experiments is the fact that while the felspar contains only a small percentage of lime, less than two-tenths of one per cent, the residue obtained on evaporating the water to dryness shows a large percentage of it, 10 to 23 per cent. The strontia was detected only when as much as five grams of felspar were used; the lithia, however, was detected in one gram, but both were easily detected in the residue. This accounts for a characteristic of our waters, i. e. the presence of strontia and lithia, and I interpret this as strong corroborative proof that, however changed the waters may be, they originally obtain the greater part of their mineral constituents from the decomposition of the felspars. The uniform presence of strontia and lithia in our waters puzzled me greatly until the results of these experiments revealed the source from which they might be derived, as I knew of no lithia or strontia-bearing mineral in the mountains which would account for their presence. Apropos to the occurrence of these elements in felspar I may add that of 271 analyses of felspars of all varieties which I have found given, only three show lithia even in traces, and only two show strontia. But being present in our case they serve to confirm the view that the felspars principally furnish the mineral constituents of the waters. The amounts of sulphates and chlorids have their own particular interest, but the same importance does not attach to them as to the silicic acid already more fully discussed.

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SCIENTIFIC INTELLIGENCE.

GEOLOGY AND MINERALOGY.

1. *U. S. Geological Survey;* CHAS. D. WALCOTT, Director.—The following publications of the Survey have been recently issued:

Monograph XLII. The Carboniferous Ammonoids of America, by JAMES PERRIN SMITH, pp 1–211, plates i–xxix, 1903.

Monograph XLIII. The Mesabi Iron-Bearing district of Minnesota, by CHARLES KENNETH LEITH; CHARLES RICHARD VAN HISE, Geologist in charge, pp. 1–316, plates i–xxxiii, figs. 1–12, 1903.

Monograph XLIV. Pseudoceratites of the Cretaceous, by ALPHEUS JOSEPH HYATT, edited by T. W. Stanton, pp. 1–351, plates i–xlvii, 1903.

Bulletin No. 205. The Mollusca of the Buda limestone, by GEORGE BURBANK SHATTUCK, with an appendix on the Corals of the Buda limestone by THOMAS WAYLAND VAUGHAN, pp. 1–94, plates i–xxvii, fig. 1, 1903.

Bulletin No. 206. A study of the Hamilton Formation of the Cayuga Lake Section in Central New York, by HERDMAN FITZGERALD CLELAND, pp. 1–112, plates i–v, figs. 1–3, 1903.

Bulletin No. 207. The action of Ammonium Chloride upon silicates by FRANK WIGGLESWORTH CLARKE and GEORGE STEIGER, pp. 1–57, 1902.

Bulletin No. 209. The Geology of Ascutney Mountain, Vermont, by REGINALD ALDWORTH DALY, pp. 122, fig. 1, pls. i–vii, 1903.

Bulletin No. 210. The correlation of Geological Faunas, a contribution to Devonian Paleontology by HENRY SHALER WILLIAMS, pp. 1–147, pl. i, 1903.

2. *On Batrachian and other footprints from the Coal Measures of Joggins, N. S.;* by G. F. MATTHEW. Bull. Nat. Hist. Soc. of New Brunswick, vol. v, No. 21 (1903).—Dr. Matthew has described certain footprints in the collections of the Natural History Society of New Brunswick. They pertain to three different types of Batrachian footprints which have received generic names from King and Marsh. The first is of a type common in the Coal Measure sandstones and the other two have been referred to the genera Baropus and Dromopus, respectively. The following are the names of these species: *Thenaropus (?) McNaughton, Baropus imguifer, Dromopus agilis, Myriapodites,* sp.

3. *Ueber Artinit, ein Neues Mineral der Asbestgruben von Val Lanterna;* LUIGI BRUGNATELLI.—Under the name artinite is described a new hydrous magnesium carbonate. It is white in color and occurs in spherical aggregates made up of radiating fibers. Its formula was determined to be $MgCO_3.Mg(OH)_2.3H_2O$.

Sp.G. = 2·028.H = 2. Named after Dr. Ettore Artini, director of the mineralogical collection of the State Museum of Milan.—*Cent. f. Min., Geol. u. Palaeon.* 1903. No. 5.

4. *Minerals from Leona Heights, Alameda Co., California.*—The Leona Heights locality has been mined for some years for sulphuric acid ; the ore body consisting of pyrite with some chalcopyrite and their oxidation products. The latter include the new species BOOTHITE, also crystallized melanterite, pisanite and chalcanthite, and further copiopite, epsomite and alunogen. Boothite occurs massive with crystalline structure, also fibrous and rarely in incomplete crystals. The crystallization is monoclinic and the form related to that of melanterite and of pisanite, with which it may be regarded as forming an isomorphous series. Analyses of the fibrous and massive mineral, after deduction of the insoluble portion, gave concordant results and led to the formula $CuSO_4.7H_2O$ or, since six-sevenths of the water goes off above 105°, $H_2O.CuSO_4+6H_2O$. This species is named by W. T. SCHALLER after Edward Booth, Department of Chemistry, Univ. of California.—*Univ. California, Bull. Geol.*, iii, 191, 1903.

5. *Palacherite, a new mineral.*—A. S. EAKLE has named, after Dr. Charles Palache, a new hydrous basic sulphate of iron and magnesia from the Redington mercury mine, Knoxville, California. It occurs in loosely coherent aggregates of minute monoclinic crystals of a deep brick-red color. The hardness is 1·5–2, specific gravity 2·075, luster vitreous, streak pale yellow. The formula given is $Fe_2O_3.2MgO.4SO_3+15H_2O$, deduced from the following average of several analyses :

SO_3 38·37, Fe_2O_3 19·51, MgO 9·35, H_2O (above 100°) 12·75, H_2O (100°) 19·53= 99·51

—*Univ. California, Bull. Geol.*, iii, 231, 1903.